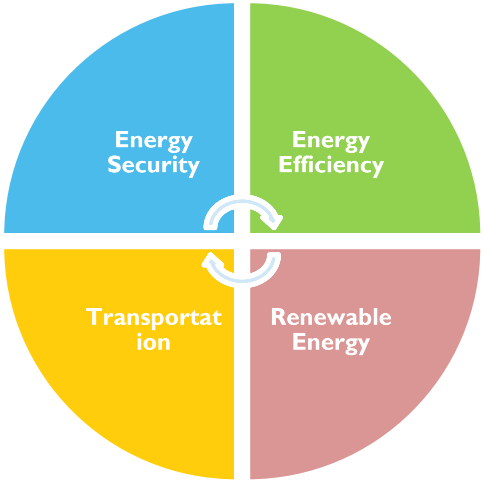
“Radiated Noise Measurements of Rhode Island Wind Turbines”

Thursday, July 17, 2014
6 – 7:30PM
University of Rhode Island, Kingston Campus
Kirk Auditorium

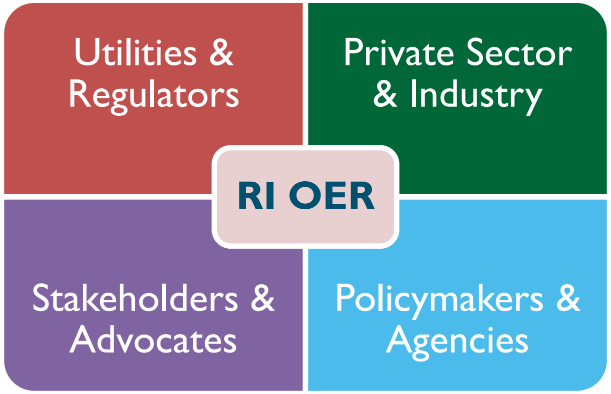
STATE OF RHODE ISLAND
OFFICE OF ENERGY RESOURCES

Rhode Island Office of Energy Resources

"Leading Rhode Island to a secure, cost-effective, and sustainable energy future"



The OER is the lead state agency on energy policies and programs



The OER works closely with diverse partners to advance Rhode Island as a national leader in the new clean energy economy

STATE OF RHODE ISLAND
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RI Wind Siting: Background

- **Land-based wind energy siting has been a major issue in Rhode Island over the past several years**
- **Several efforts have provided information and guidance related to wind siting to date:**
  - June 2012: The Division of Planning Statewide Planning Program (SPP) released "Interim Siting Factors for Terrestrial Wind Energy Systems"
  - December 2012: The Renewable Energy Siting Partnership (RESP) out of URI produced a land-based wind resource assessment, siting analysis, and online siting decision support-tools

RI Wind Siting: Current Status

- **The OER has been working with SPP during the past year and a half to follow up on addressing stakeholder input received during the SPP and RESP processes**
  - The OER commissioned two follow up studies by URI researchers: an acoustics study and a property values study
  - The scopes of these studies were presented at a public stakeholder meeting in January 2013
  - Final results of the property values study were presented at a public stakeholder meeting in December 2013
- **The outcomes of these studies will help inform any further guidance from the State regarding land-based wind energy siting**

Today

- URI Research Associate Professor of Ocean Engineering Dr. Harold “Bud” T. Vincent will present findings on the results of radiated noise measurements made at existing wind turbines operating in Rhode Island

Radiated Noise Measurements of Installed Wind Turbines throughout Rhode Island

Harold "Bud" Vincent
Research Associate Professor
Department of Ocean Engineering
University of Rhode Island

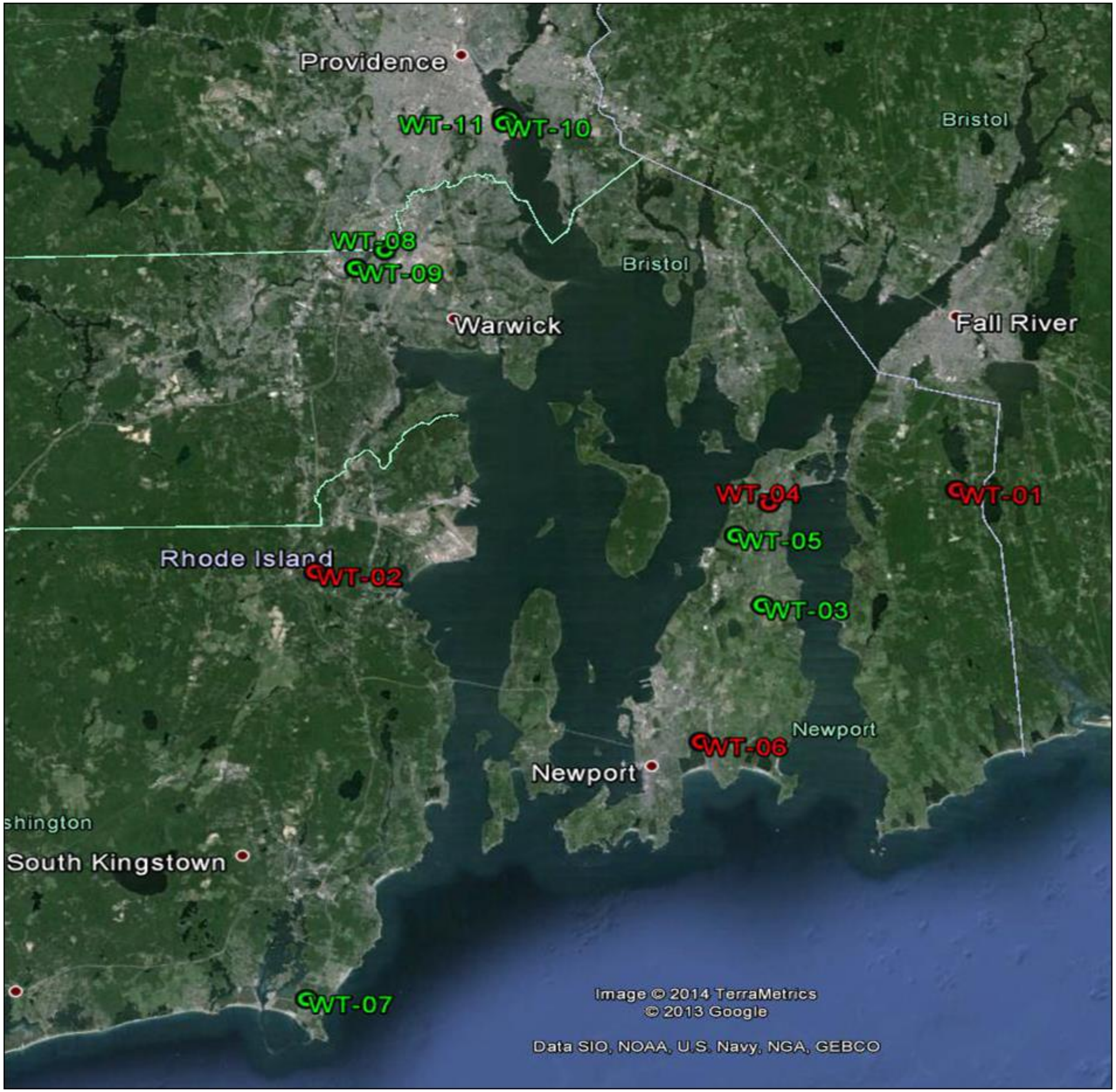
OVERVIEW

- There are 12 Wind Energy Systems (> 100 kW) presently installed in RI
- No (limited) baseline noise measurement data exist for these sites
- URI visited several operational sites and collected repeated noise measurement data recordings
- This data will serve to inform the draft siting guidelines

RI Wind Turbine Locations

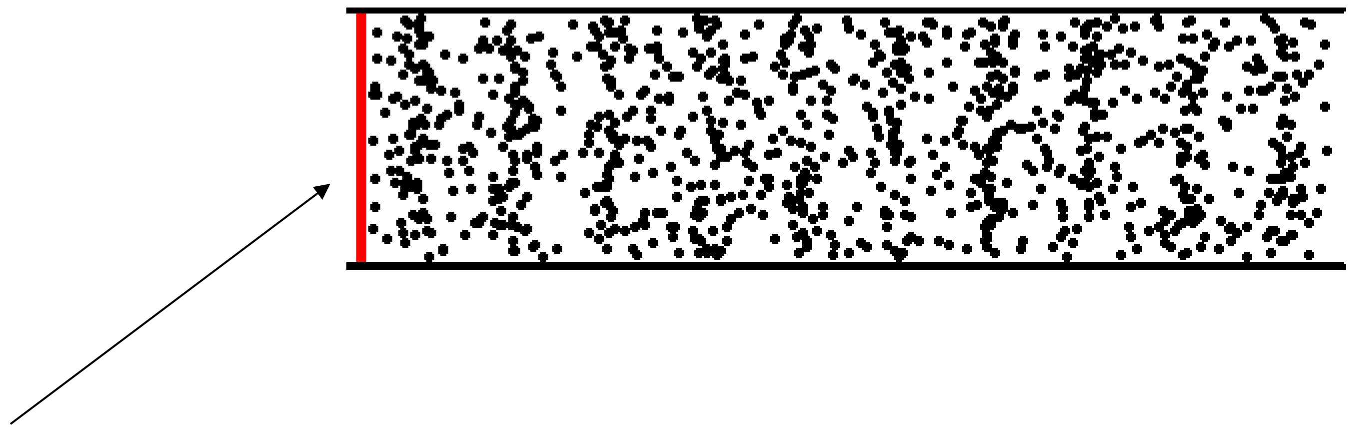
	Name	Power (kW)	Height (ft)	Longitude	Latitude
1	Sandywoods Farm - Tiverton	275	231	-71.15188	41.62307
2	North Kingstown Green	1500	402	-71.48685	41.58166
3	Portsmouth - Hodges Badge	250	197	-71.25495	41.56644
4	Portsmouth - High School	1500	336	-71.25139	41.61434
5	Portsmouth - Abbey	660	240	-71.26866	41.59906
6	Middletown Aquidneck Corporate Park	100	157	-71.28673	41.50218
7	Narragansett - Fishermen's Memorial	100	157	-71.49060	41.38080
8	Warwick - New England Tech	100	157	-71.45146	41.73277
9	Warwick - Shalom Housing	100	157	-71.46646	41.72367
10	Providence - Narragansett Bay Commission #1	1500	360	-71.38991	41.79270
11	Providence - Narragansett Bay Commission #2	1500	360	-71.38683	41.79448
12	Providence - Narragansett Bay Commission #3	1500	360	-71.38971	41.79524

RI Wind Turbine Locations



ACOUSTICS 101

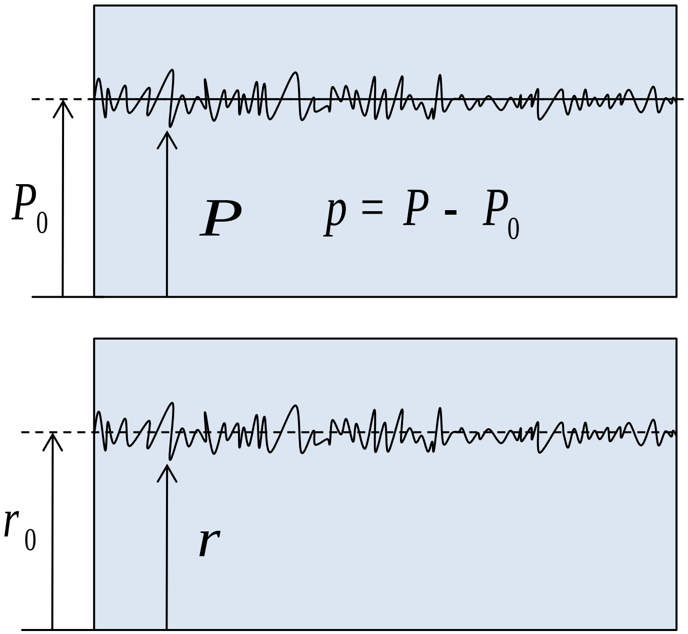
SOUND: Mechanical wave motion in an elastic medium



VIBRATING DIAPRAGHM
SOUND SOURCE

Basic Longitudinal Wave

ACOUSTICS 101



P_0 : Ambient Pressure (Pa, psi, bar, inHg, mmHg)

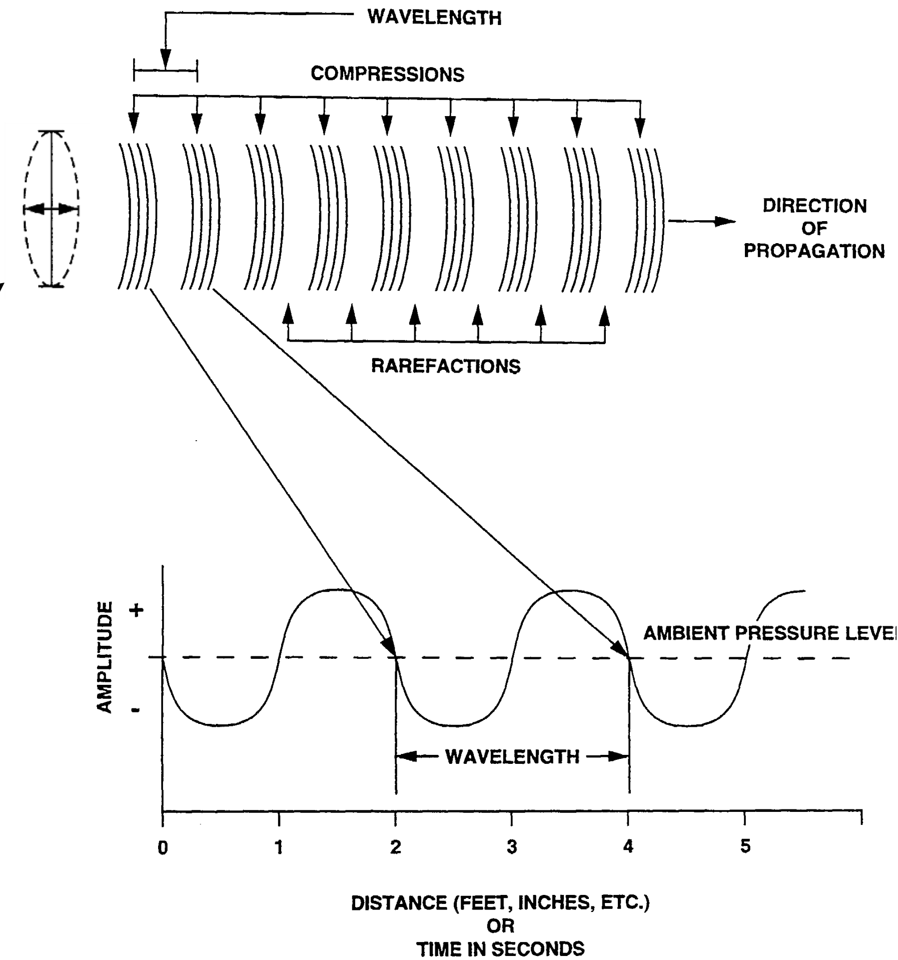
P : Instantaneous Pressure (Pa)

p : Acoustic Pressure (Pa)

$1 \text{ Pa} = 1 \ {}^{N}\!/_{m^2} = 0.000145 \text{ psi}$

- Average P_0 is normally 1 bar (100,000 Pa, 14.7 psi, 30 inHg)
- P_0 changes slowly with time due to weather
- Hurricane Wilma October 2005 88,200 Pa (12.79 psi) in eye
- P_0 is considered constant for duration of acoustic waves

ACOUSTICS 101



VIBRATING DIAPRAGHM
SOUND SOURCE

ACOUSTICS 101

Parameter	Symbol	Units
Pressure Amplitude	p	Pa (N/m^2)
Wavelength	l	m
Period	T	s
Frequency	f	Hz (1/s)
Sound Speed	c	m/s
Particle Velocity	u	m/s
Particle Displacement	x	m

$$\boxed{\begin{aligned} f &= 1/T \\ c &= l\,f \end{aligned}}$$

$$\boxed{\begin{aligned} p &= u / rc \\ p &= x / 2p\,f\,rc \end{aligned}}$$

ACOUSTICS 101
(PRESSURE)

The amount of force per unit area

A scalar quantity that creates a force acting normal to surface area

MKS units: pascal (= 1 N/m^2)

In air acoustics, use $\mu Pa = 10^{-6}$ Pa

Sound pressure level unit: decibel (dB), referenced to 20 μPa (considered to be threshold of human hearing @1 kHz)

ACOUSTICS 101 (INTENSITY)

Power per unit area

A vector quantity that points in the direction of power flow

MKS units: watt/meter^2

Plane Wave: $I = P^2/\rho C$

- P = rms pressure
- ρ = density
- C = speed of sound

ACOUSTICS 101
(DECIBEL)

Intensity expressed in dB is Sound Pressure Level (SPL):

$$SPL = 10 \log(I/I_{ref})$$

since $I \alpha P^2$,

$$SPL = 10 \log(P^2/P_{ref}^2)$$
$$= 20 \log(P/P_{ref})$$

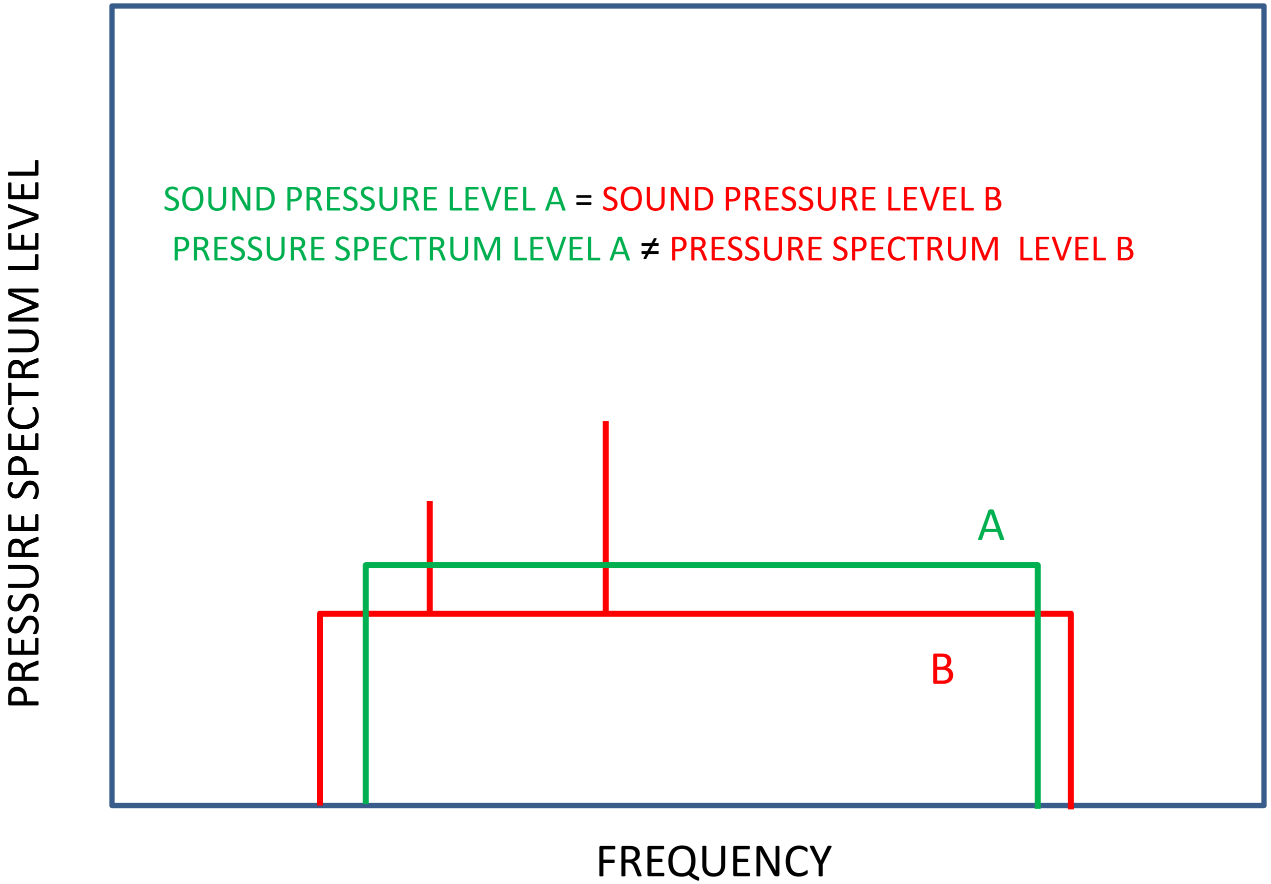
ACOUSTICS 101

Source of sound	Sound pressure* (pascals)	Sound level (decibels)
Shockwave (distorted sound waves > 1 atm; waveform valleys are clipped at zero pressure)	>101,325	>194
Theoretical limit for undistorted sound at 1 atmosphere environmental pressure	101,325	194
Stun grenades	6,000–20,000	170–180
Simple open-ended thermoacoustic device[1]	12,619	176
.30-06 rifle being fired 1 m to shooter's side	7,265	171
M1 Garand rifle being fired at 1 m	5,023	168
Rocket launch equipment acoustic tests	4000	165
LRAD 1000Xi Long Range Acoustic Device at 1 m[2]	893	153
Jet engine at 1 m	632	150
Threshold of pain	63.2	130
Vuvuzela horn at 1 m[3]	20	120
Risk of instantaneous noise-induced hearing loss	20	120
Jet engine at 100 m	6.32–200	110–140
Non-electric chainsaw at 1 m[4]	6.32	110
Jack hammer at 1 m	2	100
Traffic on a busy roadway at 10 m	0.2–0.632	80–90
Hearing damage (over long-term exposure, need not be continuous)[5]	0.356	85
Passenger car at 10 m	$(2–20)\times10^{-2}$	60–80
EPA-identified maximum to protect against hearing loss and other disruptive effects from noise, such as sleep disturbance, stress, learning detriment, etc.[6]	6.32×10^{-2}	70
Handheld electric mixer		65
TV (set at home level) at 1 m	2×10^{-2}	60
Washing machine, dishwasher[7]		42–53
Normal conversation at 1 m	$(2–20)\times10^{-3}$	40–60
Very calm room	$(2–6.32)\times10^{-4}$	20–30
Light leaf rustling, calm breathing	6.32×10^{-5}	10
Auditory threshold at 1 kHz[5]	2×10^{-5}	0

ACOUSTICS 101

SPL vs. PSL

- Two sounds with same SPL but they would be perceived differently by a listener (i.e. they sound different).
- Why? Because they have different Pressure Spectrum Level (PSL).
- PSL can also vary with time



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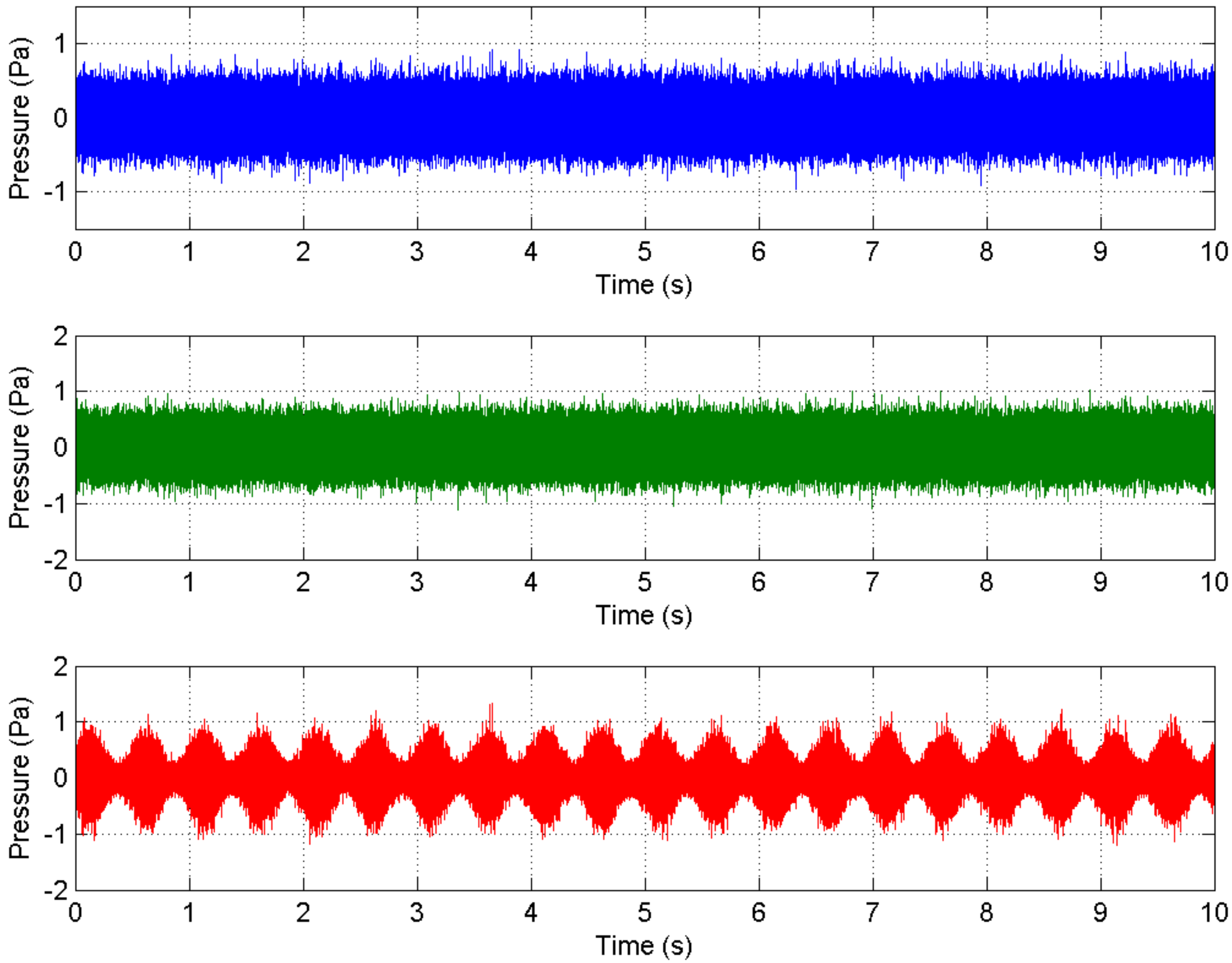

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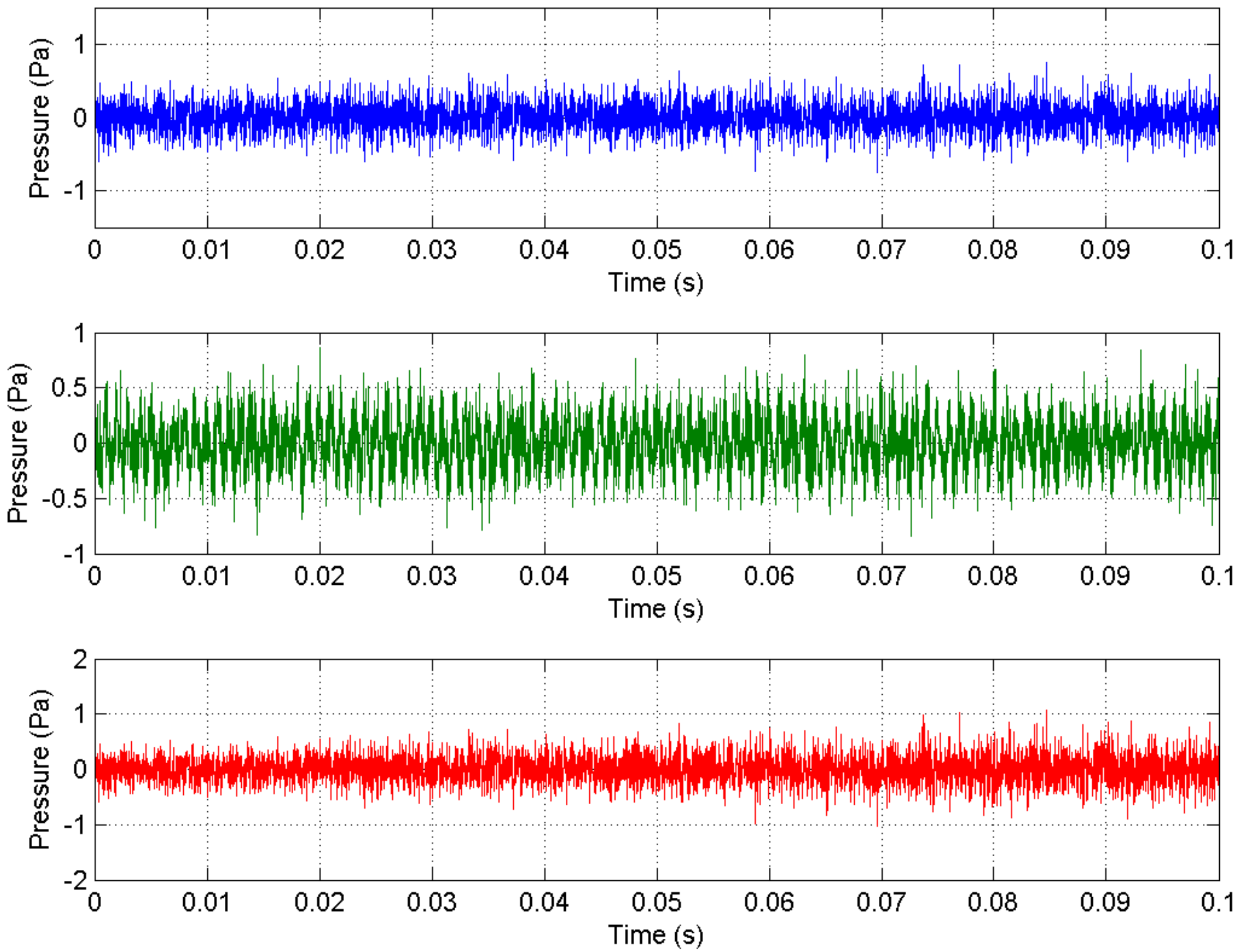

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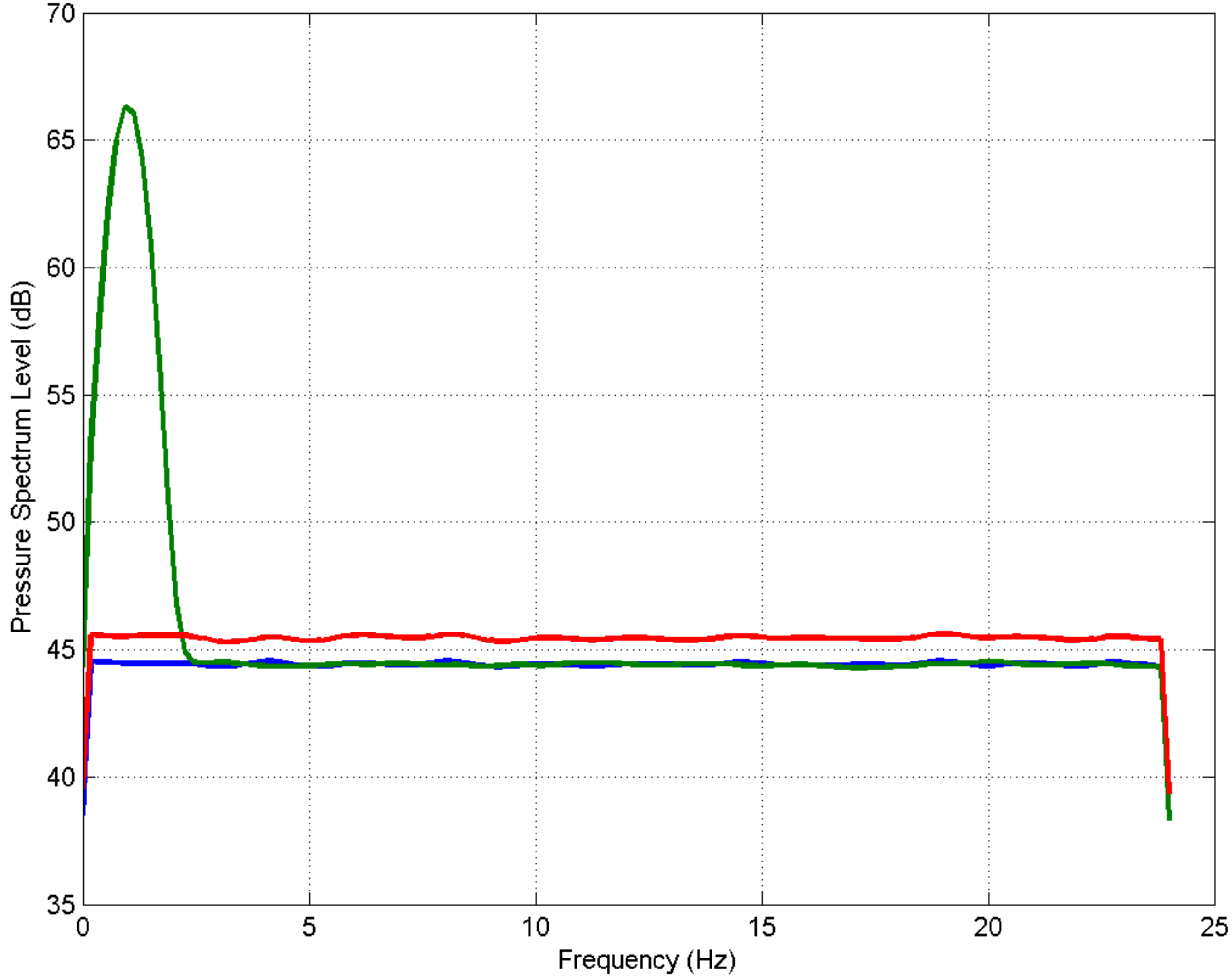
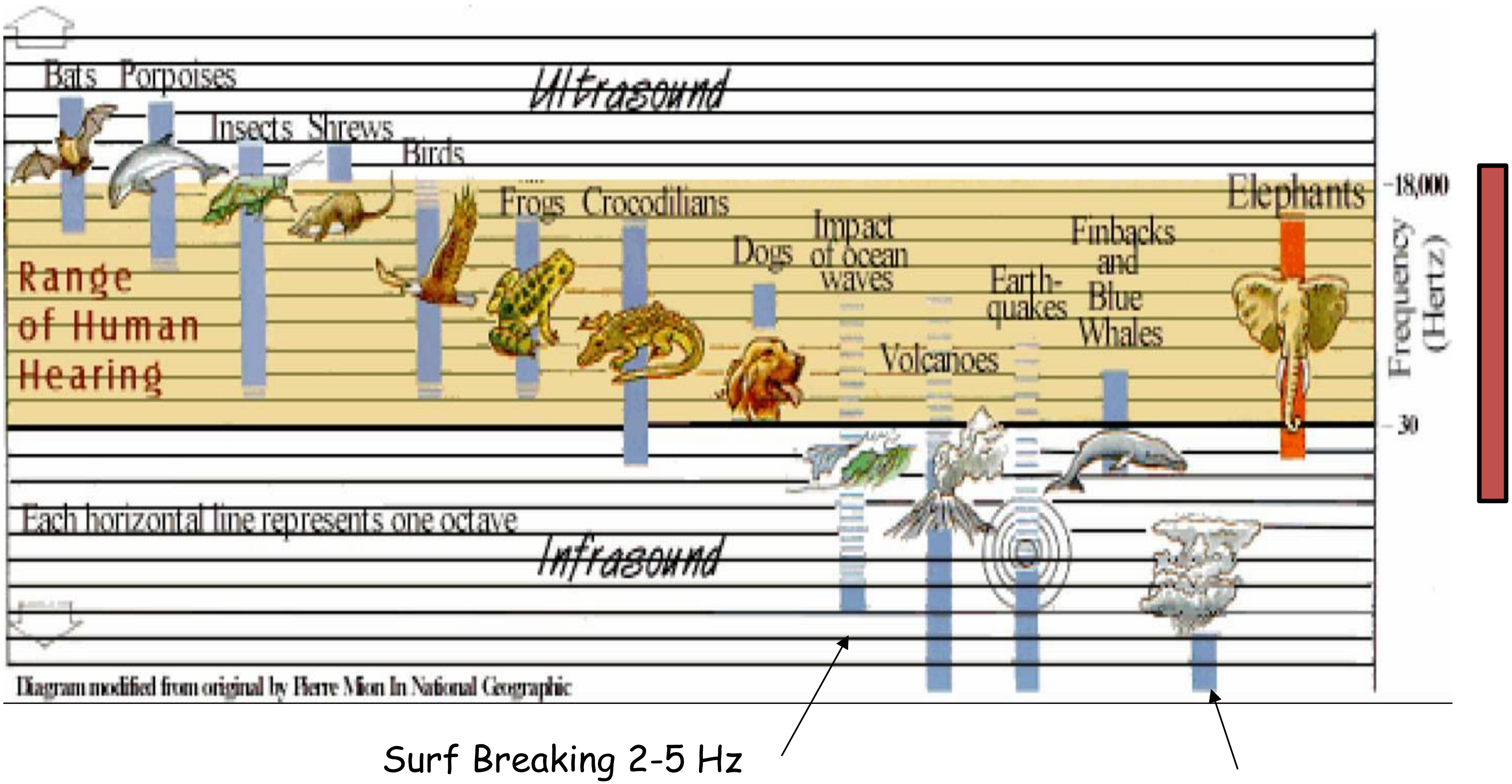


ACOUSTICS 101

THE SOUND SPECTRUM



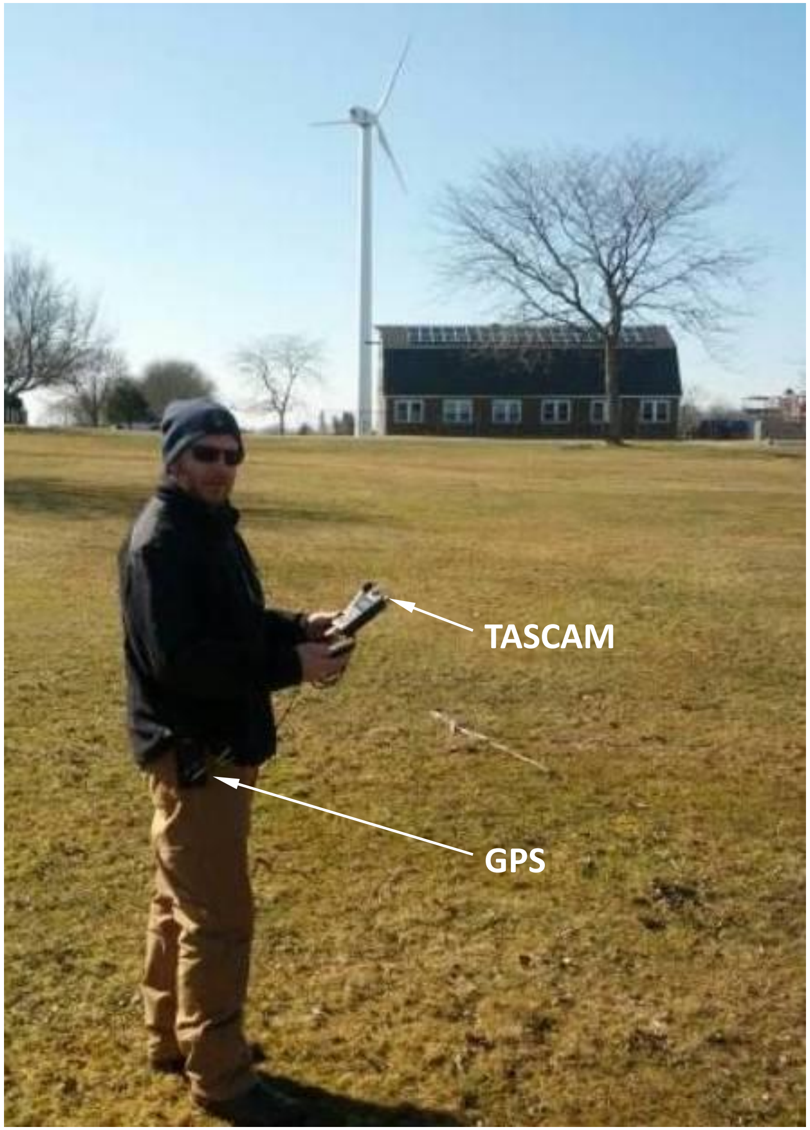
METHODOLOGY

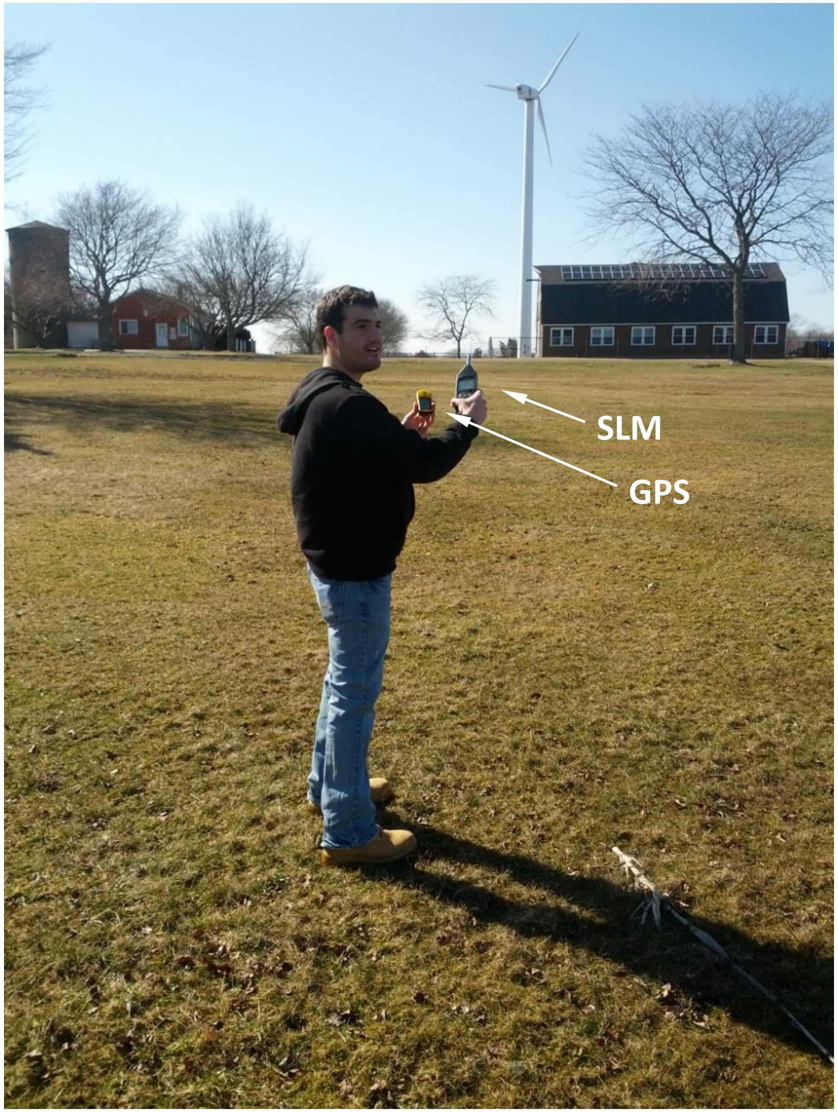
- At each site collect data from multiple instruments:
  - Sound Level Meter (SLM)
  - Full Bandwidth Audio Recorder (20 Hz – 20 kHz) with 2 microphones (TASCAM)
  - Infrasound microphones and recorder (0.5 Hz – 2 kHz)
  - Global Positioning System (GPS) Receiver
- The SLM and TASCAM are portable and can collect data continuously while moving around the property.
- Infrasound recording system remains stationary at a fixed location relative to the turbine.
- GPS is used to measure position and synchronize with SLM/TASCAM systems.
- Different microphones and recording systems were used to cover different frequency bands.

METHODOLOGY

- Each site visited multiple times from March 2013 – July 2013
- Data collected under a variety of conditions
- Recordings encompass both Audio and Infrasound frequency regions
  - Raw pressure recordings – Audio band (20 Hz – 20 kHz)
  - Raw pressure recordings – Infrasound Band (< 20 Hz)
  - Sound Level Meter recordings
- Performed equipment calibration
  - Simultaneous data acquisition of microphone and recording systems to controlled audio sources
  - Concentration on Low Frequency and Infrasound regions
  - Linear Frequency Modulated (LFM) 1 Hz – 200 Hz
- Revised data collection and analysis (stakeholder input)
  - Mapping of noise field (e.g. Sound Level vs. Distance)
  - Required simultaneous measurement of acoustic data and GPS position data
  - Required time synchronization between instruments
  - MUCH more extensive data processing (> 10x)

METHODOLOGY



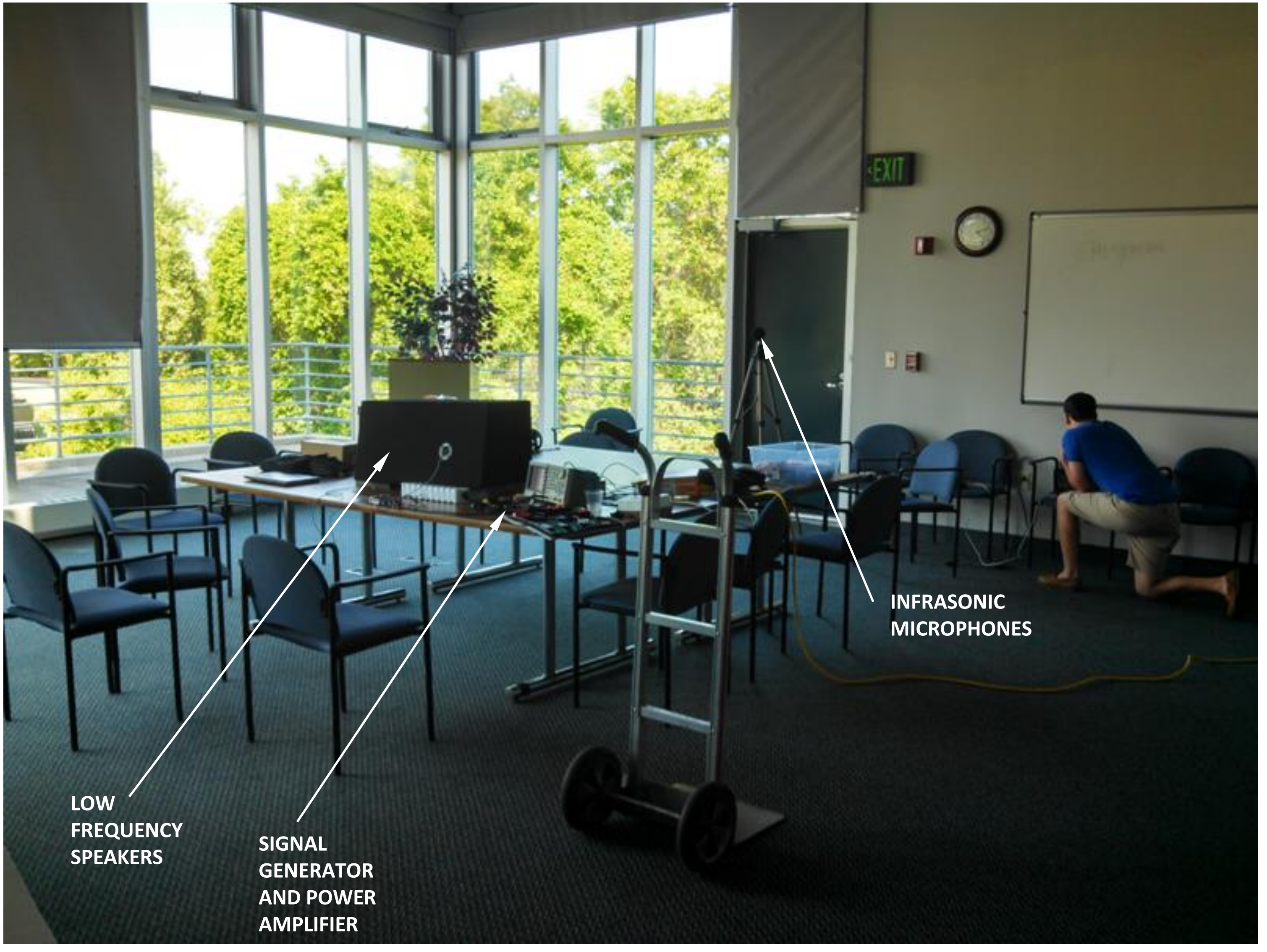


METHODOLOGY

RESULTS – CALIBRATION

- Calibration was performed in a laboratory setting at URI concurrent with the field measurements to compare SLM and TASCAM to infrasound system (previously calibrated at factory – traceable to National Inst. of Science and Technology (NIST), formerly Nat. Bur. Standards)
- Consisted of simultaneously exposing to each system (SLM, TASCAM, Infrasound) to a single sound source created from a function generator, power amplifier and loudspeaker system.
  - Signals consisted of tones and sweeps
  - Concentration on Low Frequency and Infrasound regions
- Objective was to establish sensitivity of TASCAM system and identify any weaknesses of SLM

RESULTS – CALIBRATION



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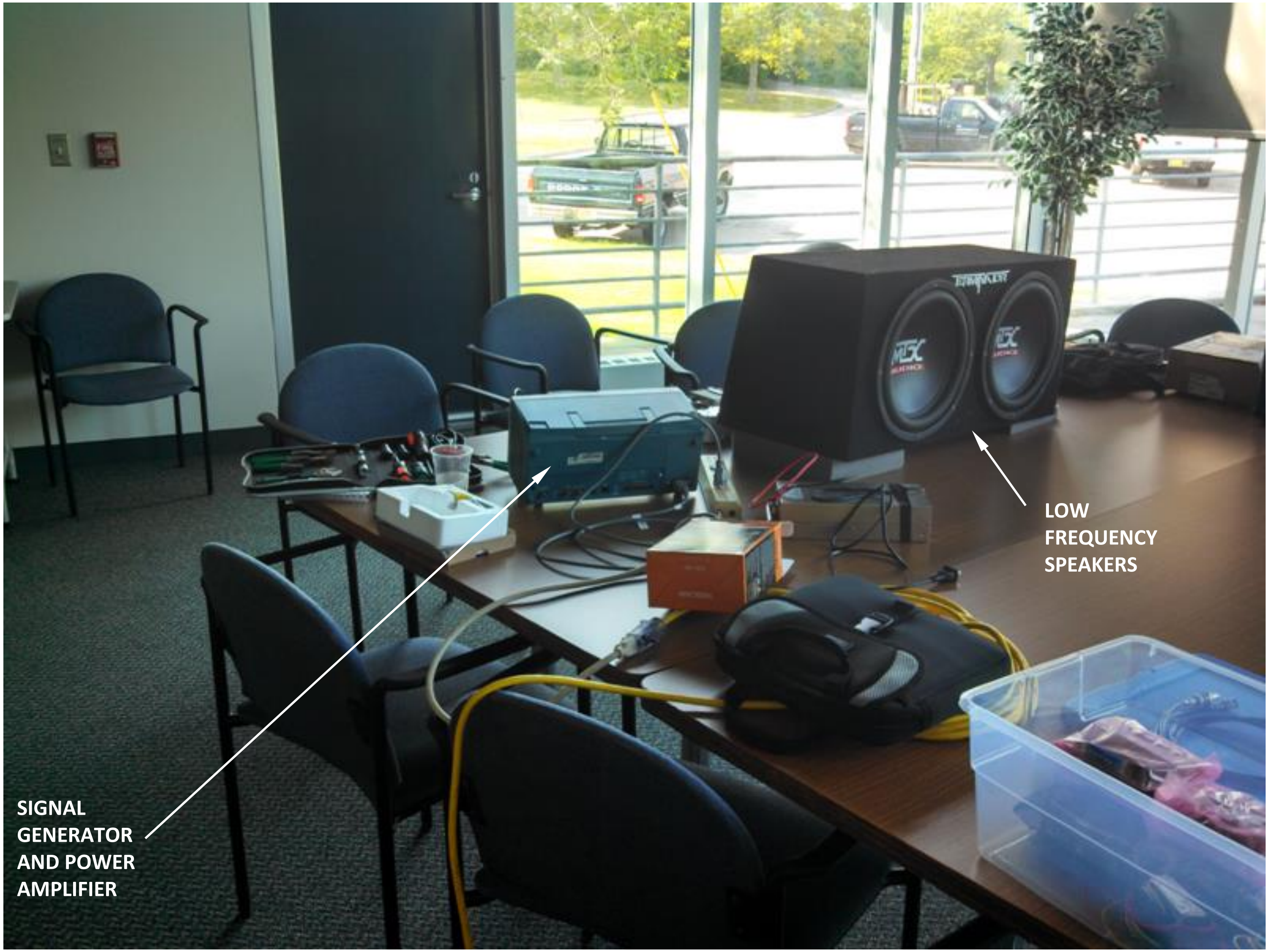

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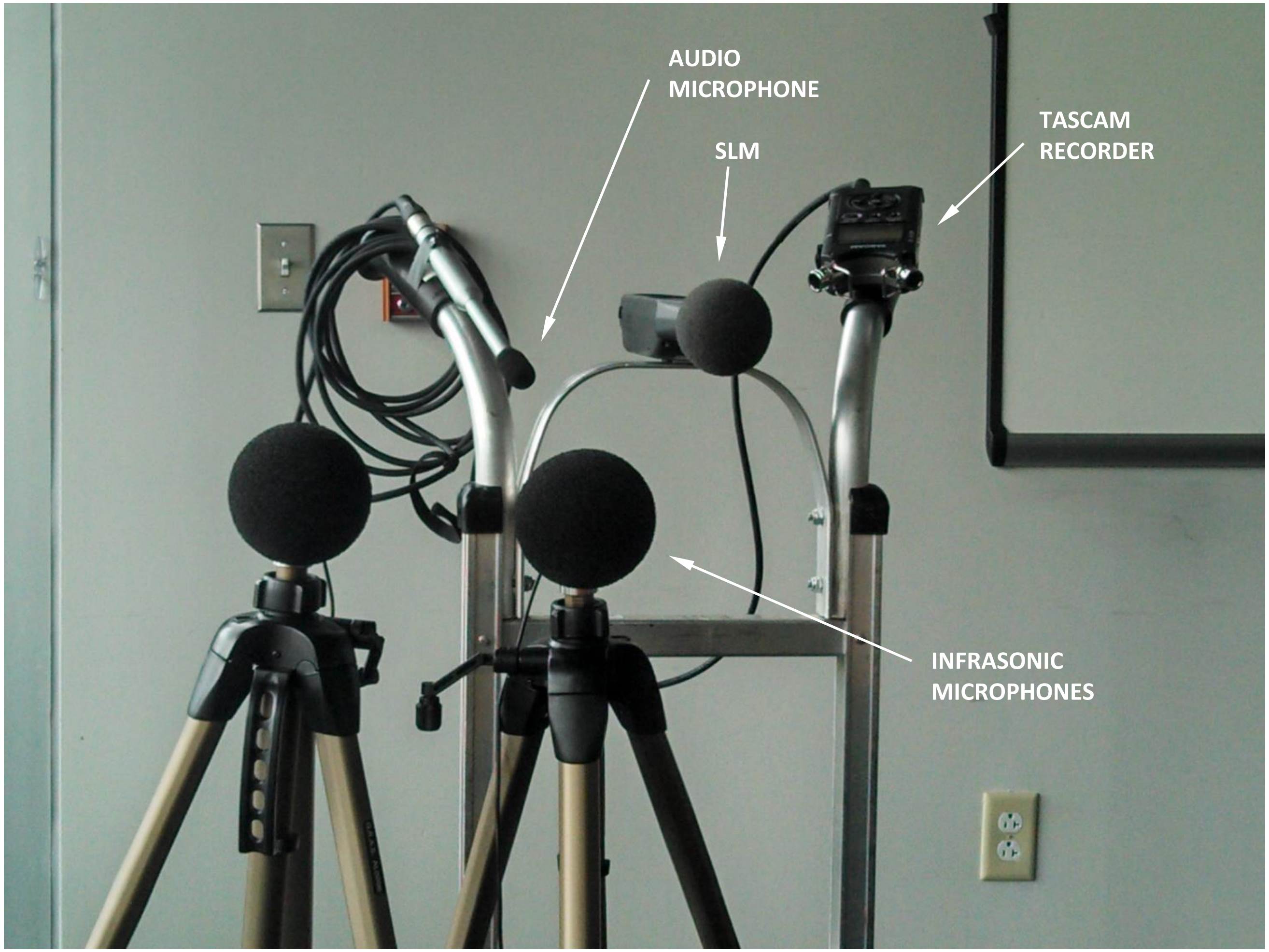

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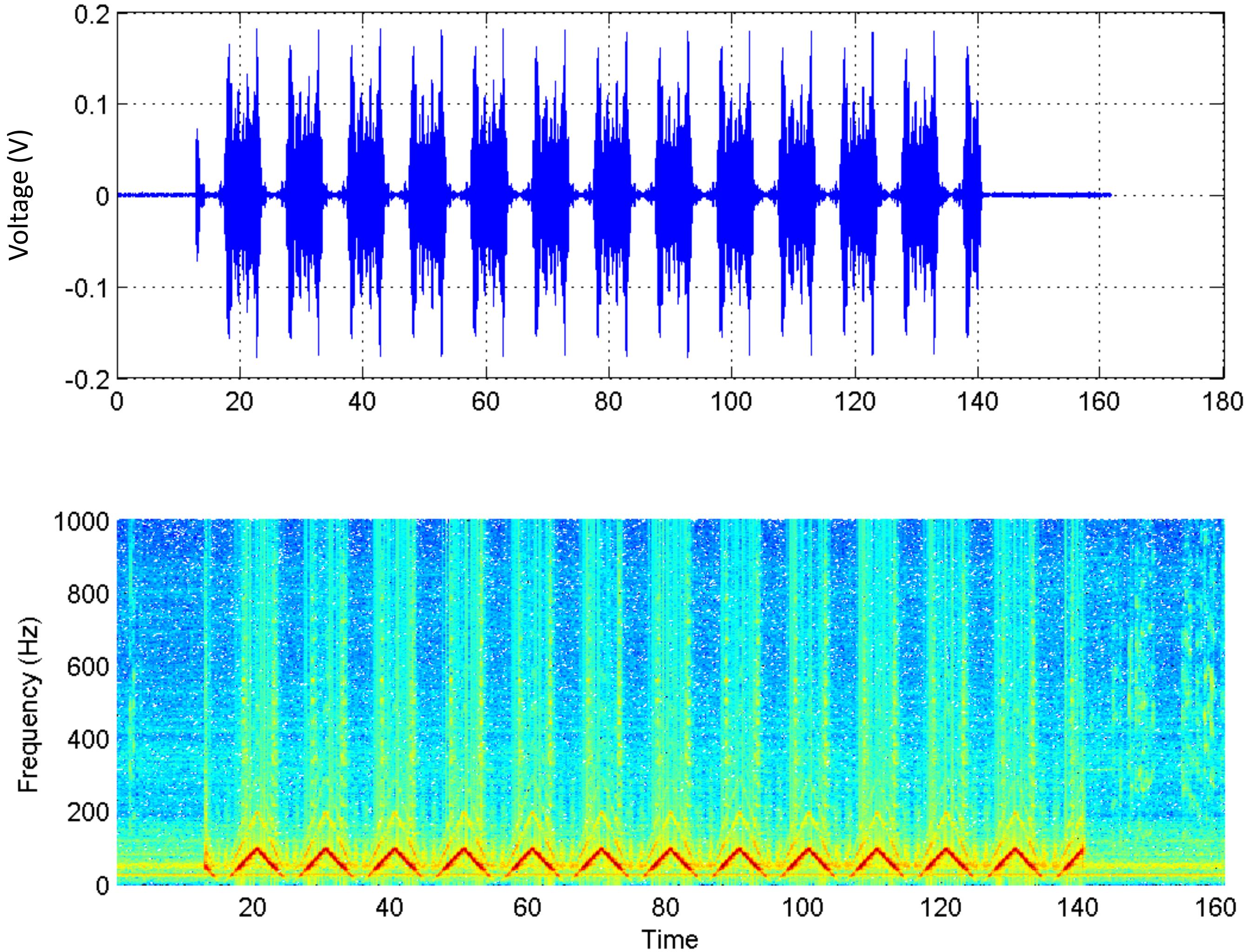

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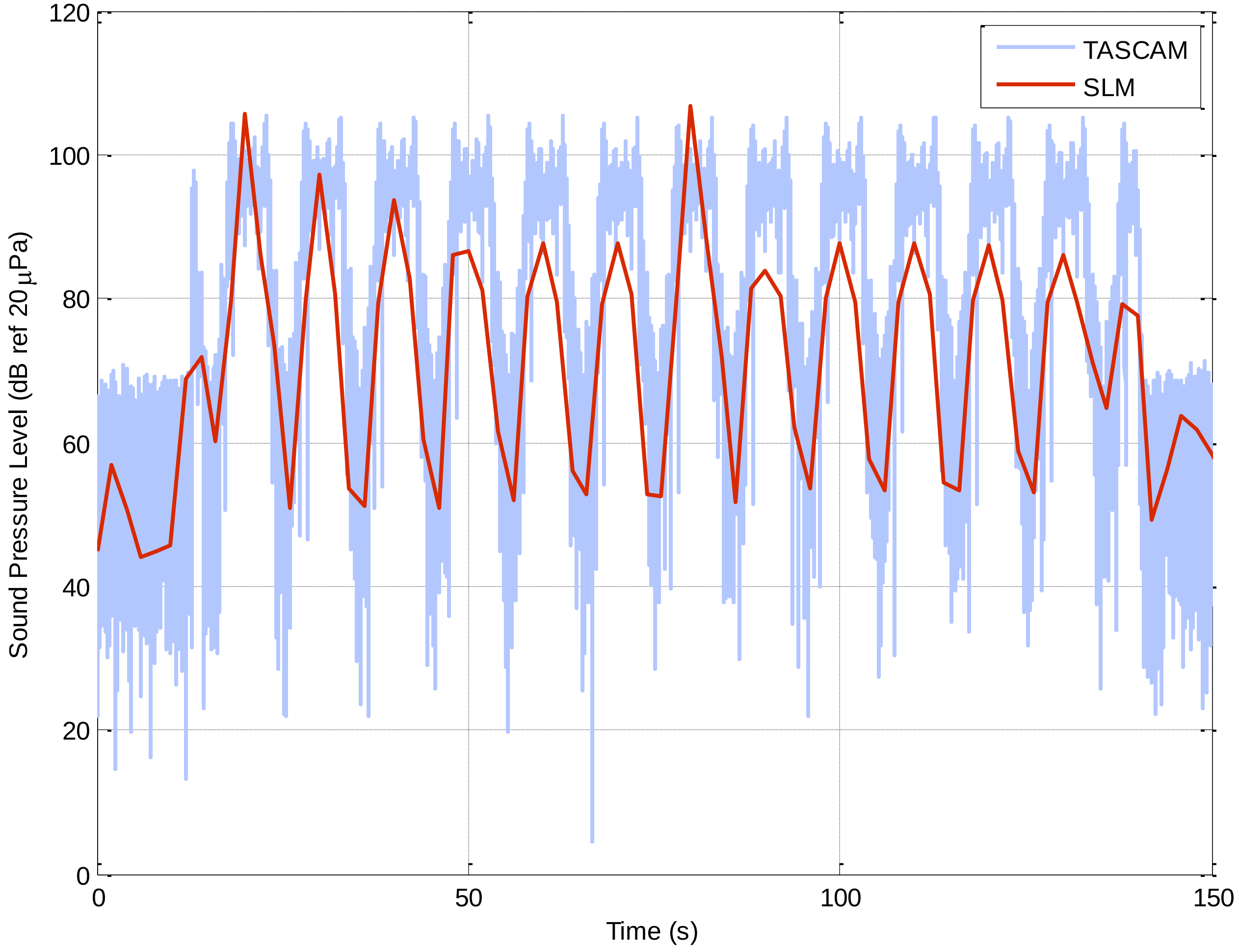


RESULTS – CALIBRATION

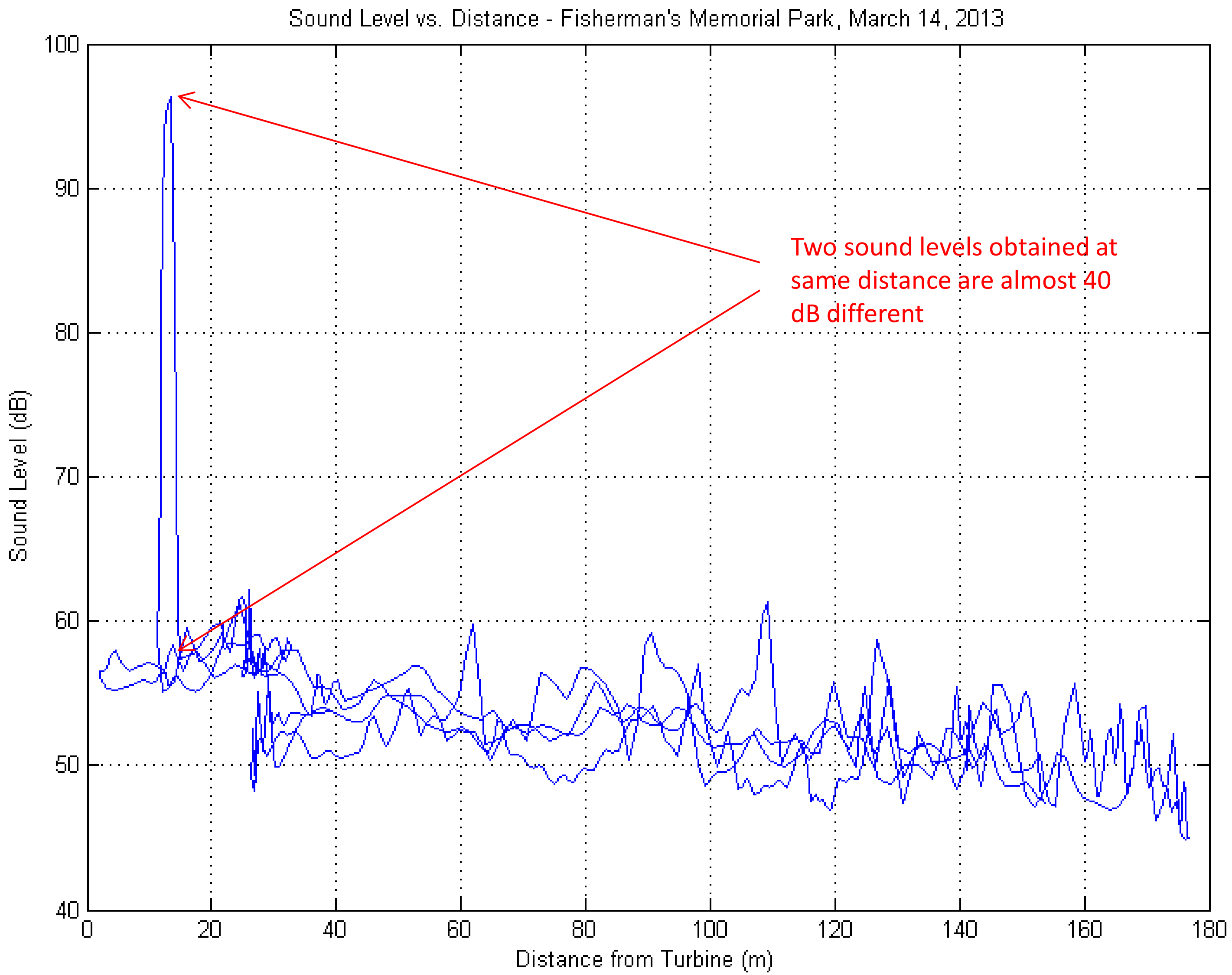
- Calibration revealed that the SLM was inconsistent in its measurement values
- SLM SPL reading varied depending on frequency content of signal and SLM settings (FAST, SLOW)
- SLM SPL reading varied for same settings varied from one trial to another
- Despite limitations, it was still used in all field measurements for completeness and because it required no additional effort to do so.
- SLM had been used in some field measurements prior to the calibration

RESULTS – SOUND LEVEL METER

- Purpose was to traverse regions around the wind turbines, continuously recording Sound Level and GPS
- Map the sound field
- Show changes in sound level vs. distance
- Show changes in sound level vs. direction
- Does not show changes in Sound Level with Time (because we are moving)

RESULTS – SOUND LEVEL METER

RESULTS – SOUND LEVEL METER



RESULTS – SOUND LEVEL METER

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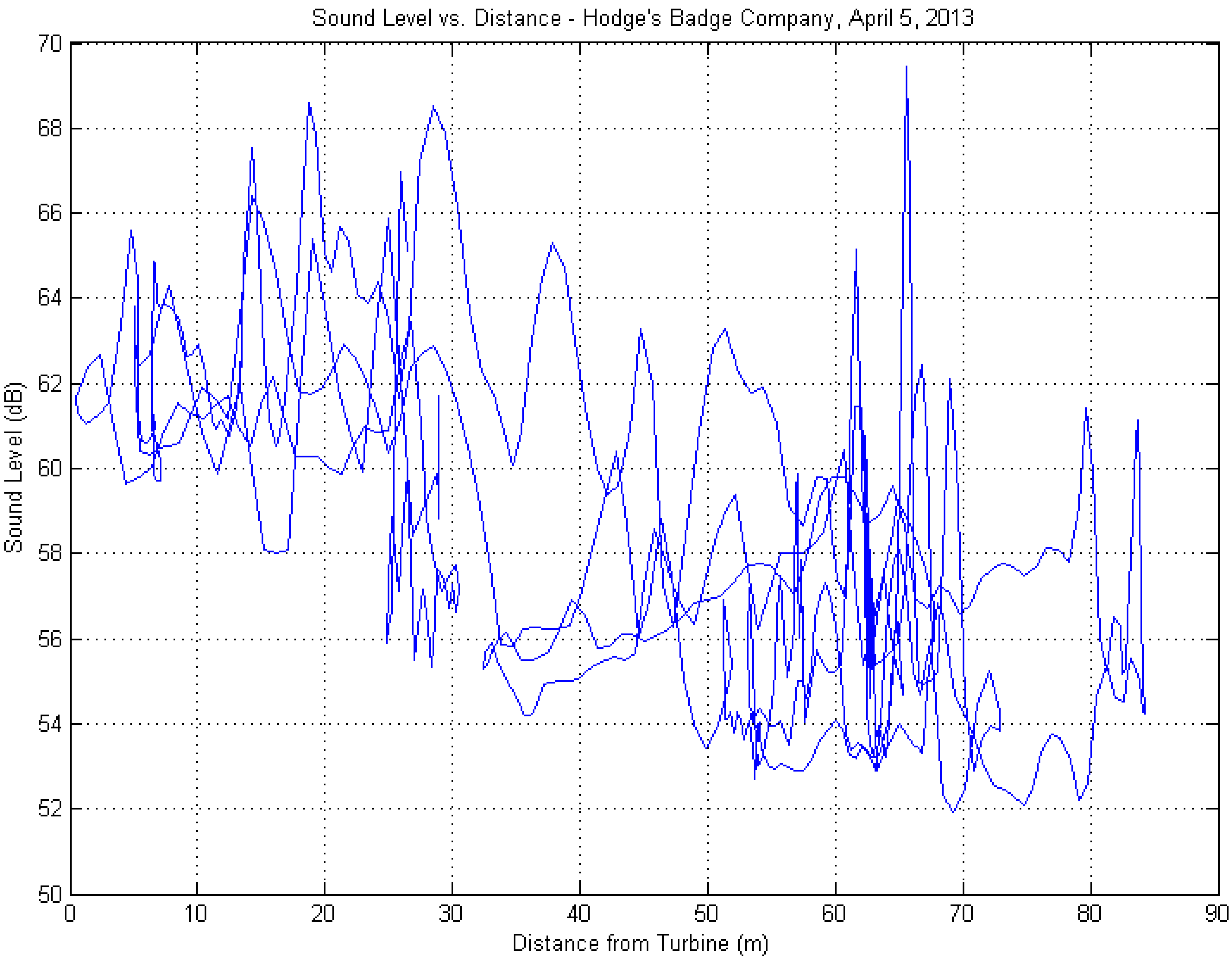

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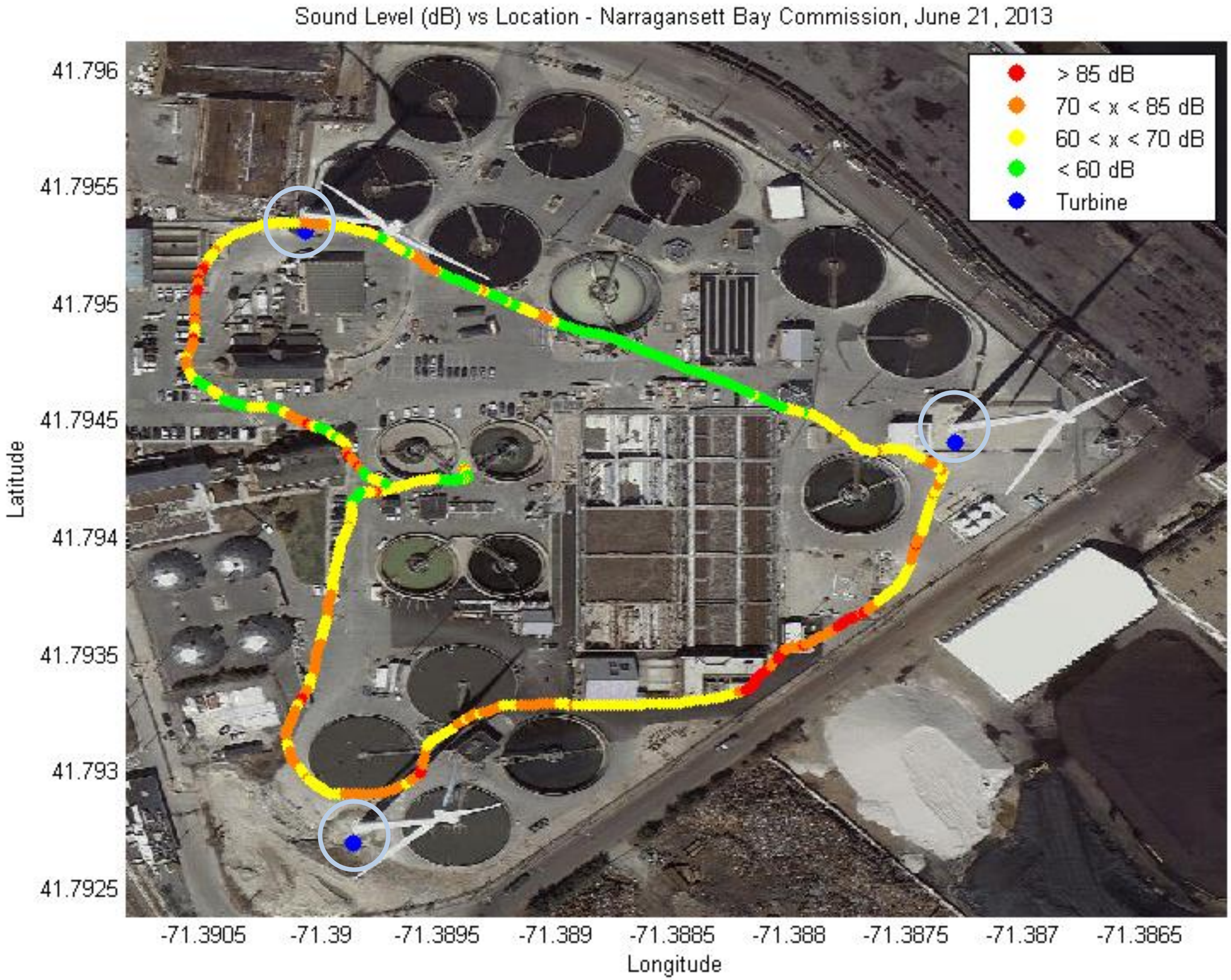

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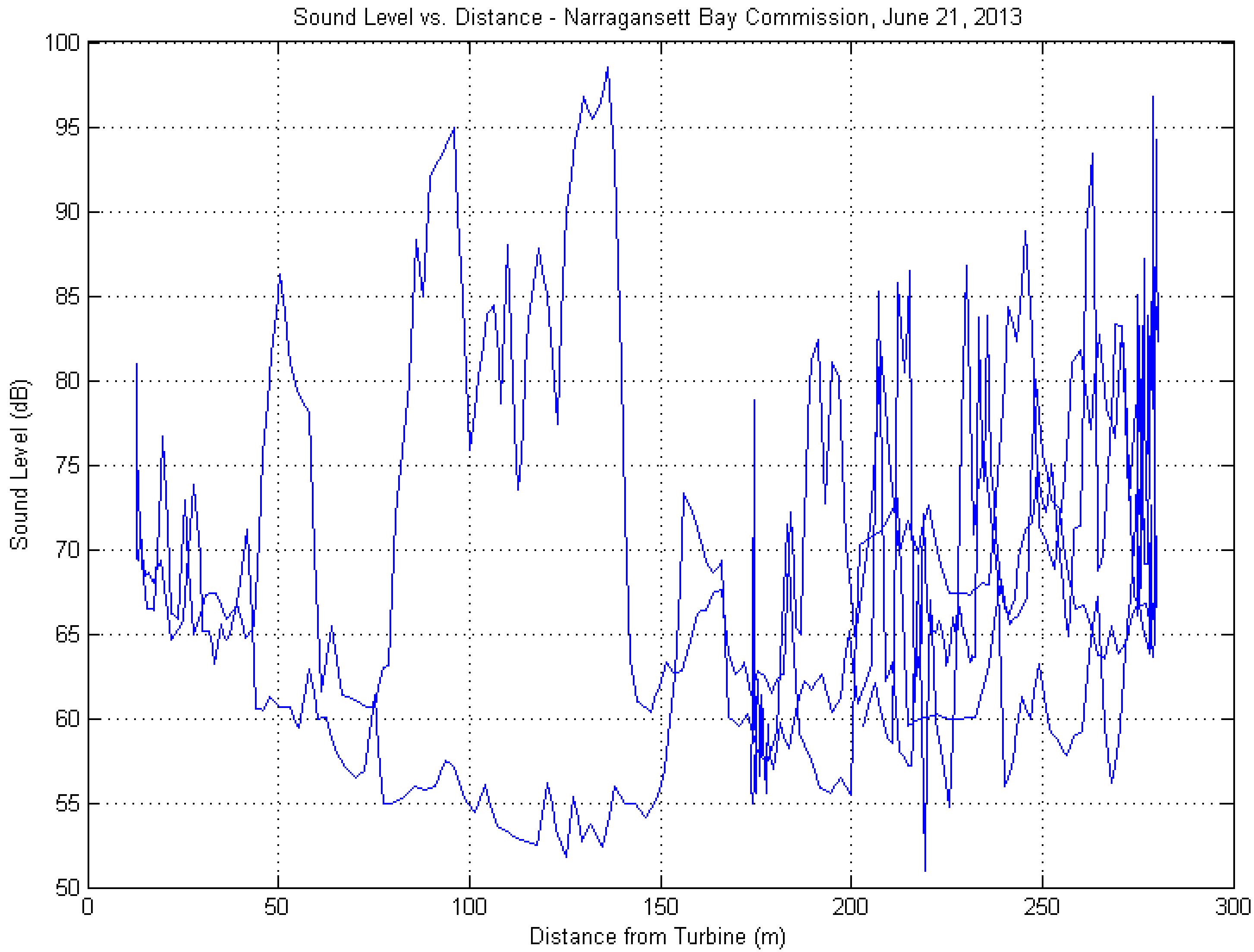


RESULTS – SOUND LEVEL METER

- Main conclusions:
- sound level can vary significantly at same distance (greater than 30 dB in one instance)
- Sound level can be higher at a further distance (or lower at a closer distance)
- Sound level can be higher/lower at same distance but in a different direction

RESULTS – INFRASOUND

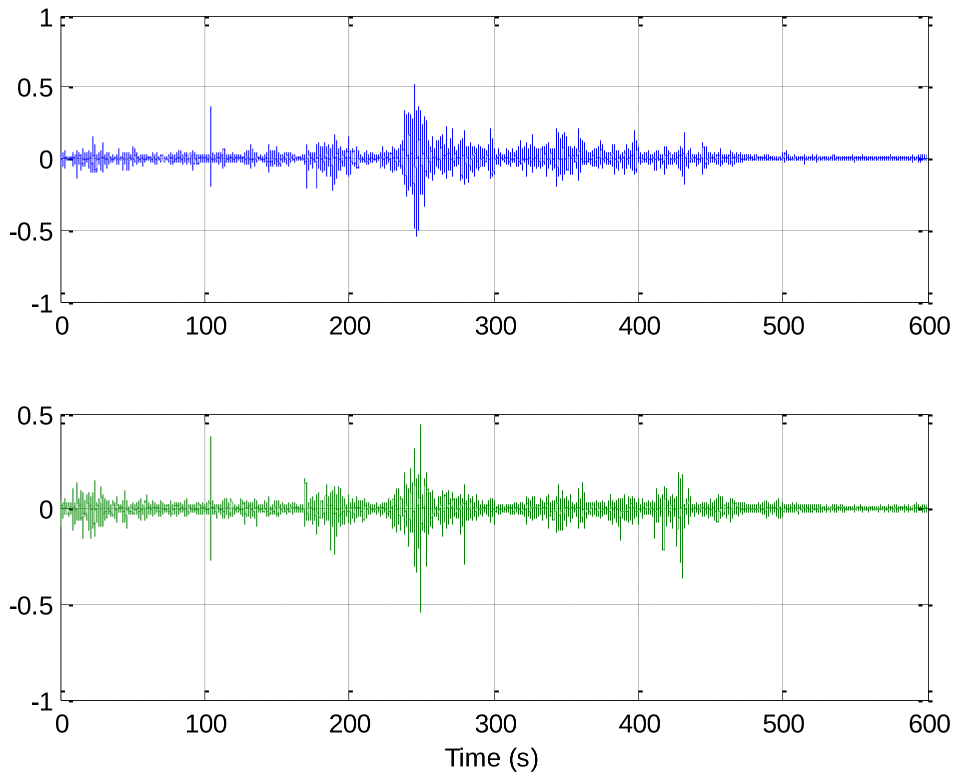
- Infrasonic data was collected at stationary locations to measure the low frequency nature of the sound
- Several minutes at one locations
  - Changes in low frequency sound levels as a function of distance and direction not measurable
  - Changes in low frequency sound levels as a function of time are measurable
- Objective was to measure low frequency sound levels not recorded by the TASCAM or SLM
- Low frequency or Infrasound can’t be effectively demonstrated in a room using standard audio equipment (amplifiers and speakers)

RESULTS – INFRASOUND

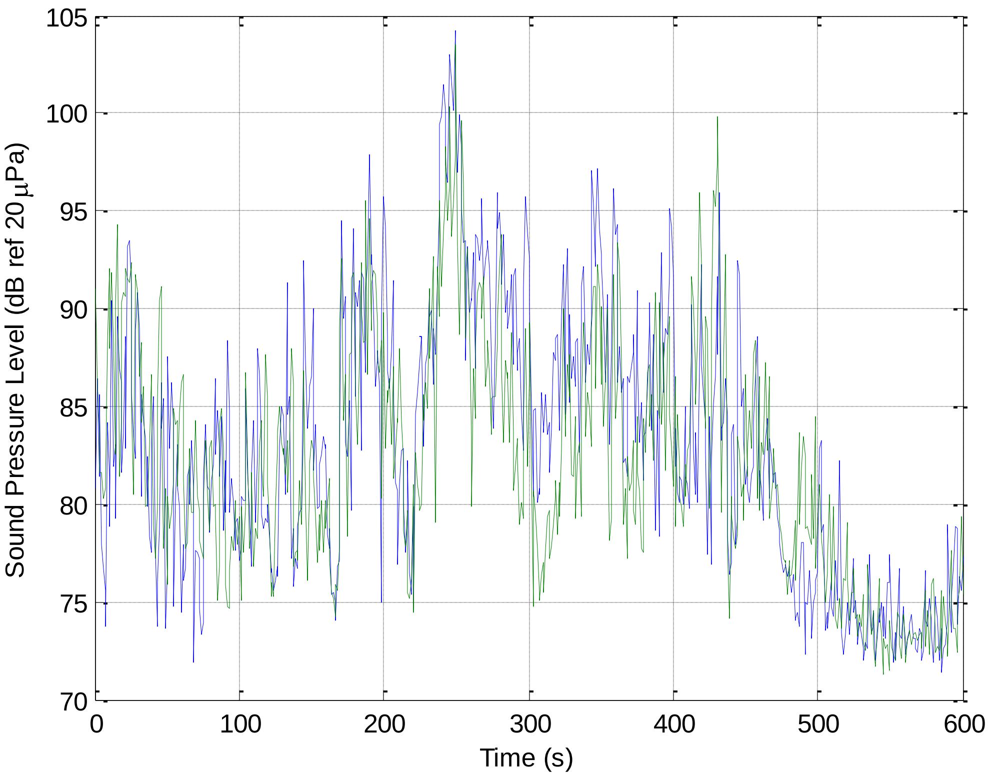
RESULTS – INFRASOUND

MICROPHONE 1

MICROPHONE 2

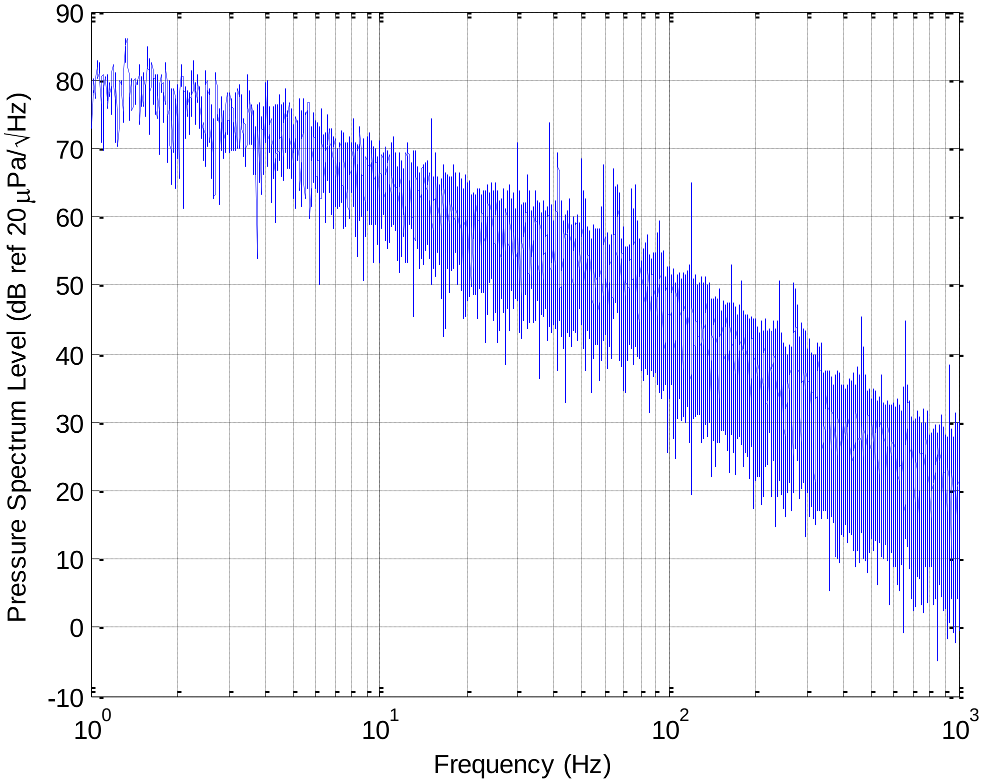


RESULTS – INFRASOUND



Note that the measured Sound Level changes with time even at a fixed location and thus fixed distance from the wind turbine

RESULTS – INFRASOUND

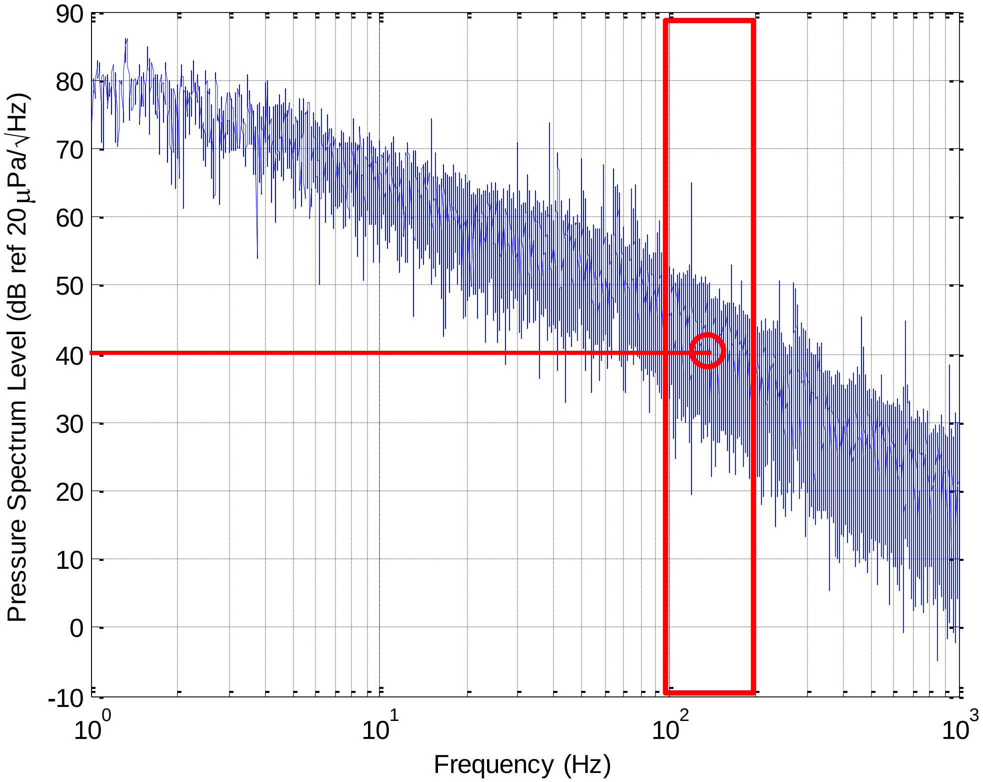


RESULTS – INFRASOUND

$$SPL = PSL + 10\log_{10}(w)$$

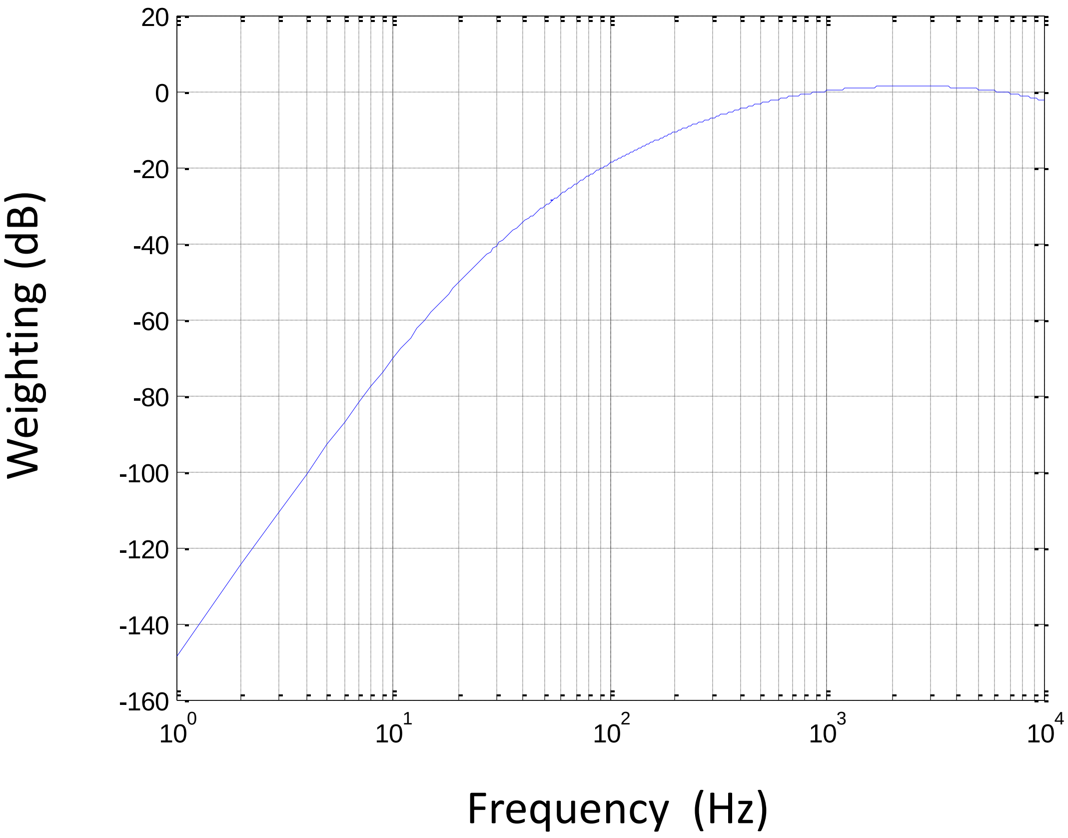
Let’s look at the band from 100 Hz to 200 Hz:

$$SPL = 40 + 10\log_{10}(100) = 60\ \text{dB}$$

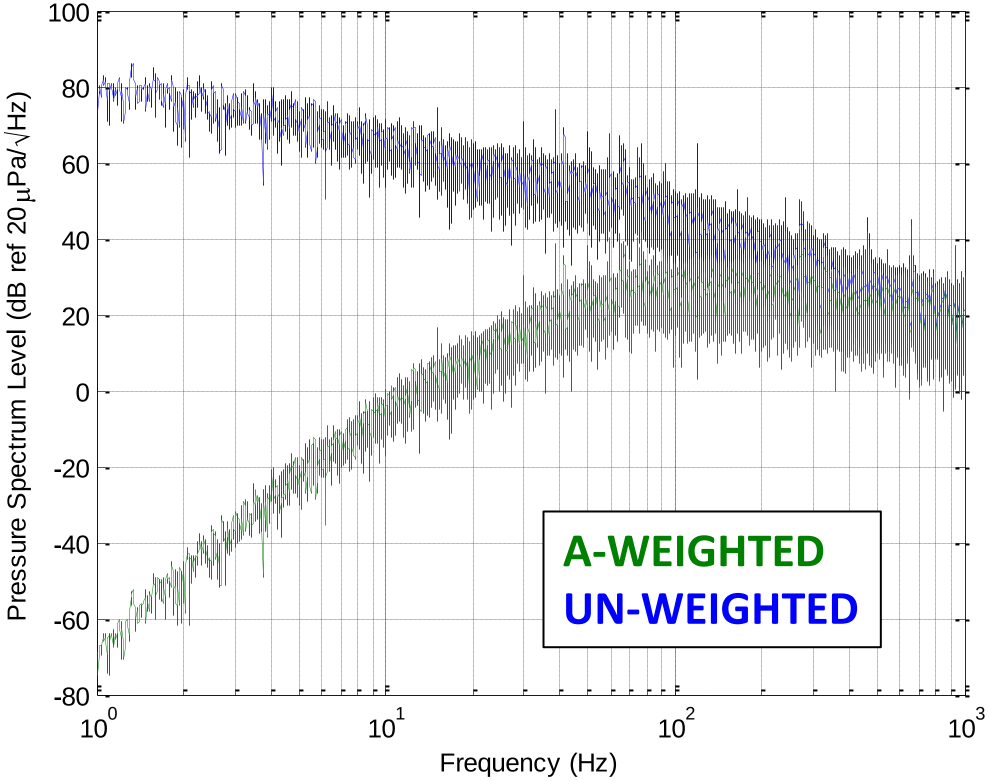


RESULTS – INFRASOUND

A WEIGHTING CURVE



RESULTS – INFRASOUND



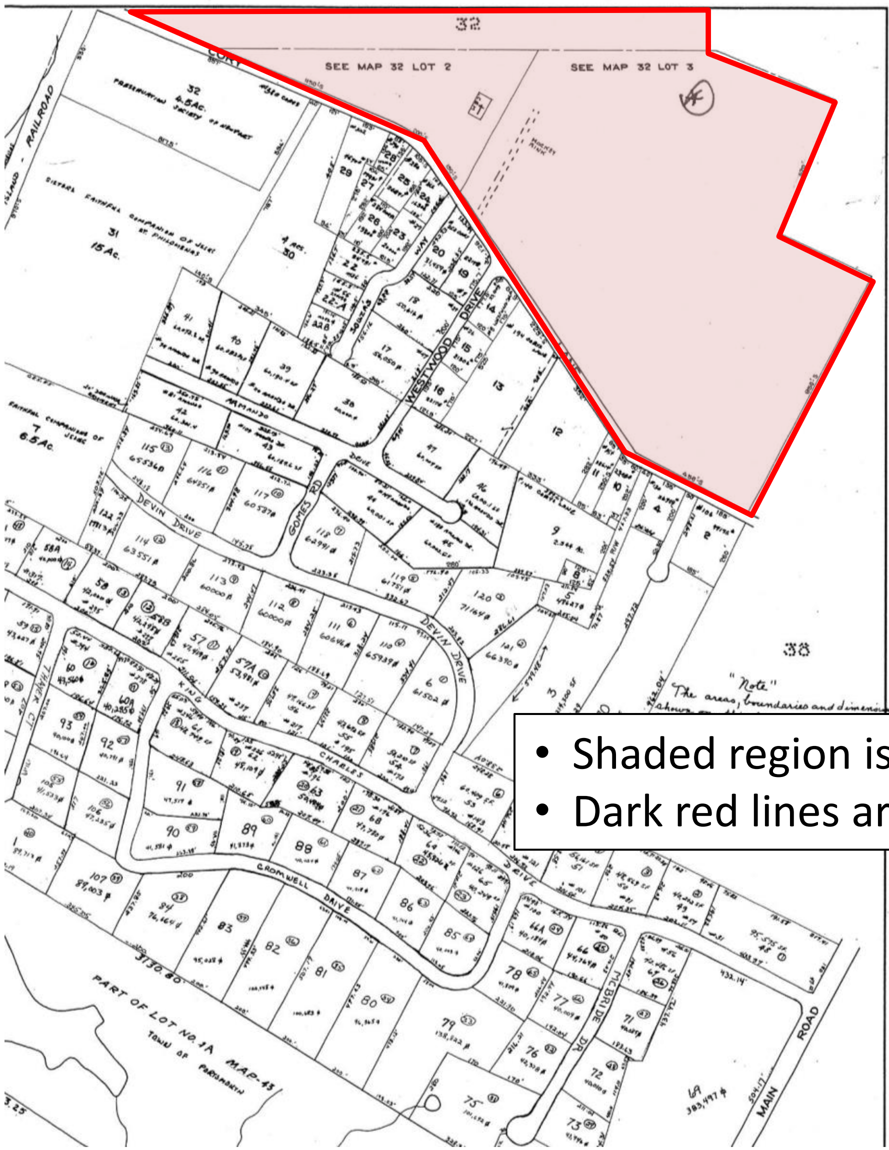
RESULTS – INFRASOUND

- The time averaged measured infrasound levels (10-20 Hz) were 90 dB ref 20 uPa
- SPL variations of 30 dB (+/- 15 dB) were observed as a function of time.
- Not captured by SLM (weighting) or by TASCAM (frequency band)

RESULTS – PROPERTY LINE MEASUREMENTS

- Measurements with TASCAM and SLM were made along the property lines
- Performed due to language contained in draft siting guidelines
- Similar to first set of SLM measurements but now performed along a specific path, the property lines surrounding the properties
- Execution of these measurements first required review of zoning maps, locating property and identifying property lines
- In the field, the measurements required navigation to traverse the property lines.
- Some property lines are not accessible due to dense vegetation and other obstacles.

RESULTS – PROPERTY LINE MEASUREMENTS



- Shaded region is Portmouth Abbey property
- Dark red lines are the property lines

RESULTS – PROPERTY LINE MEASUREMENTS

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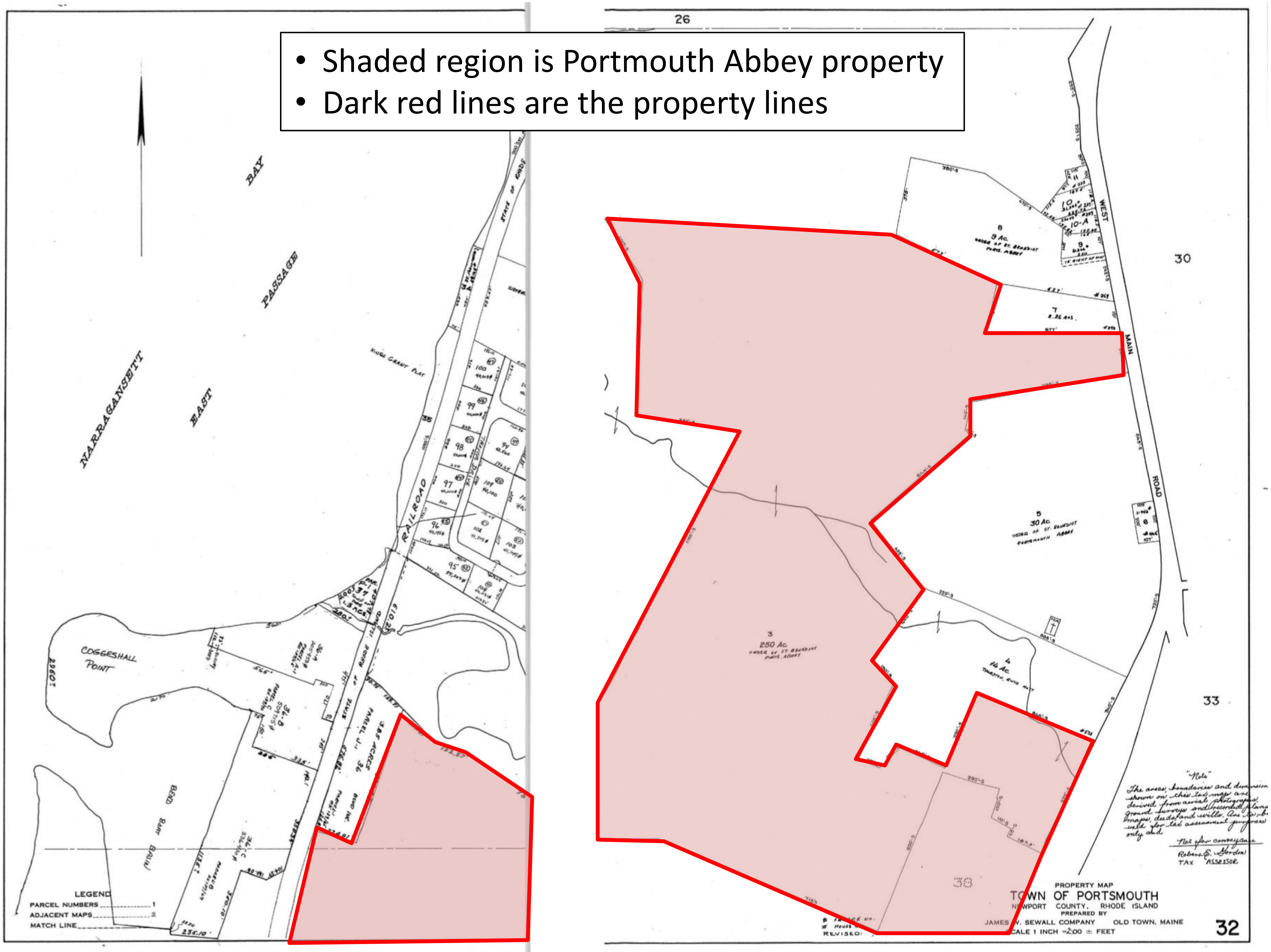

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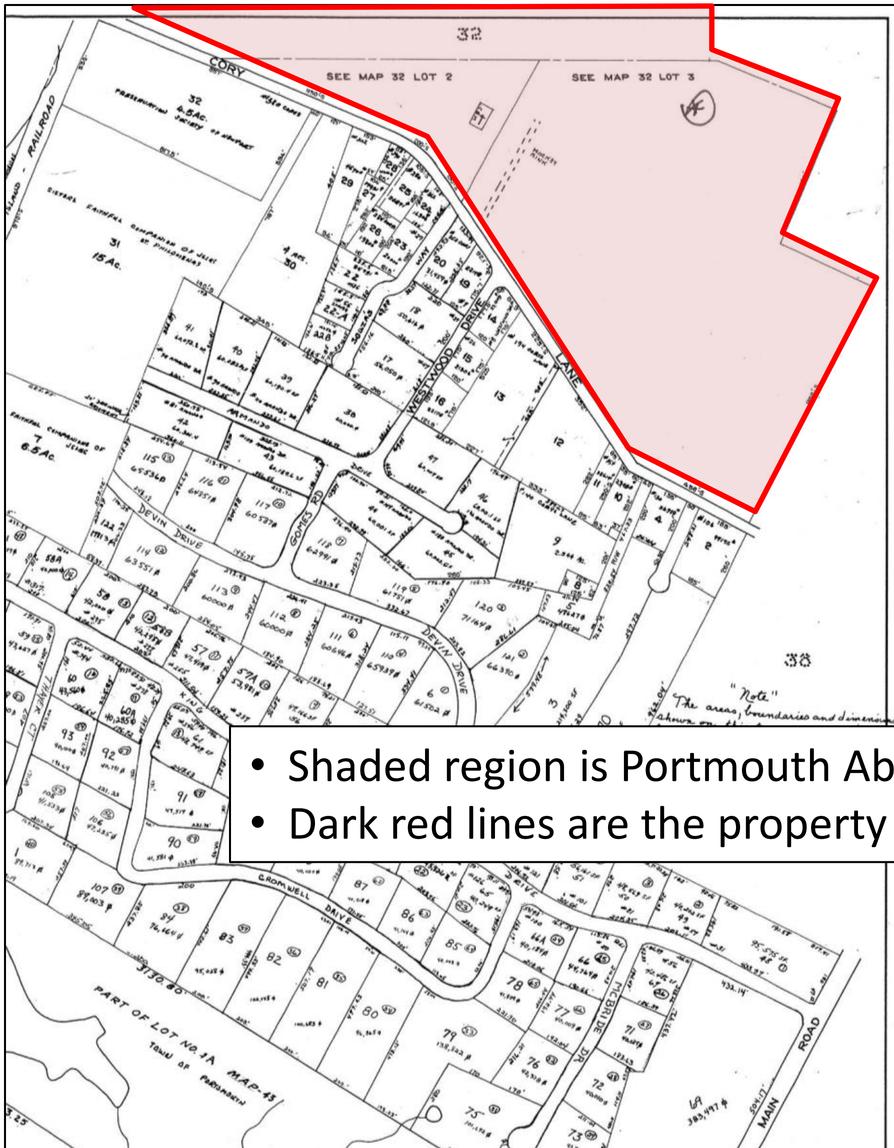

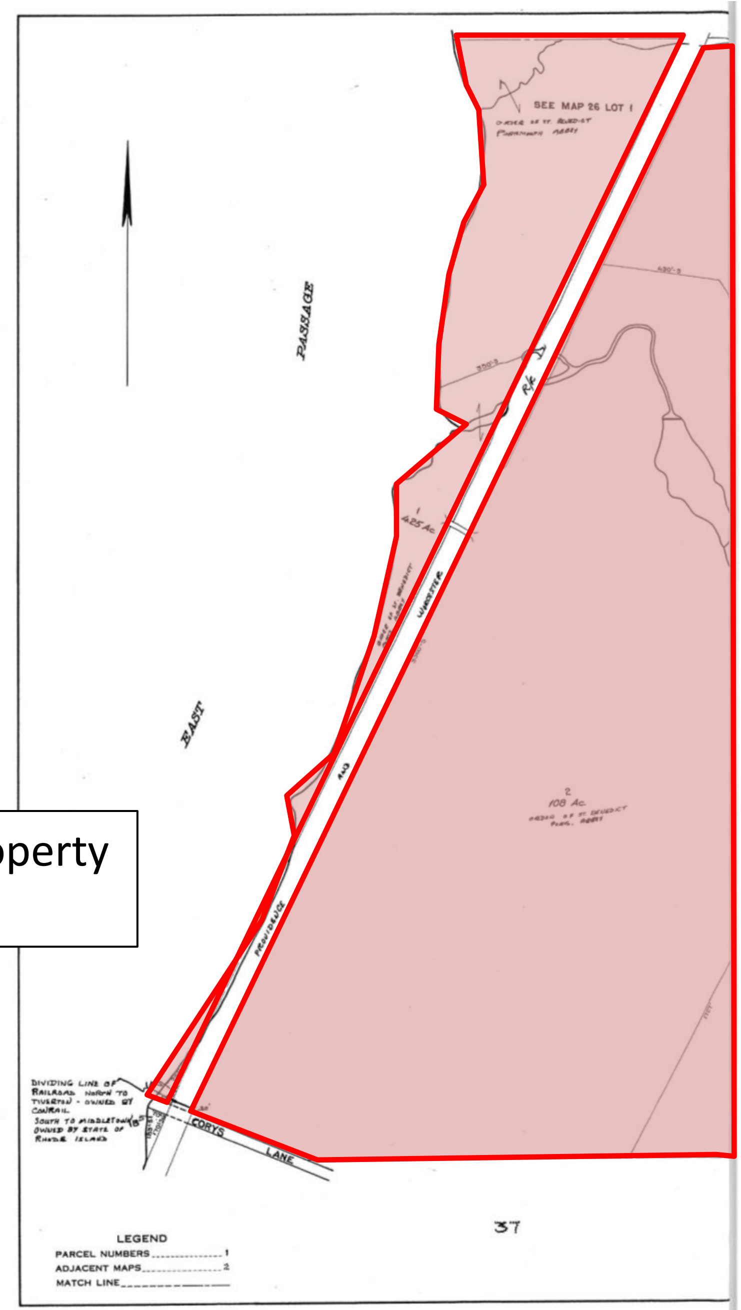

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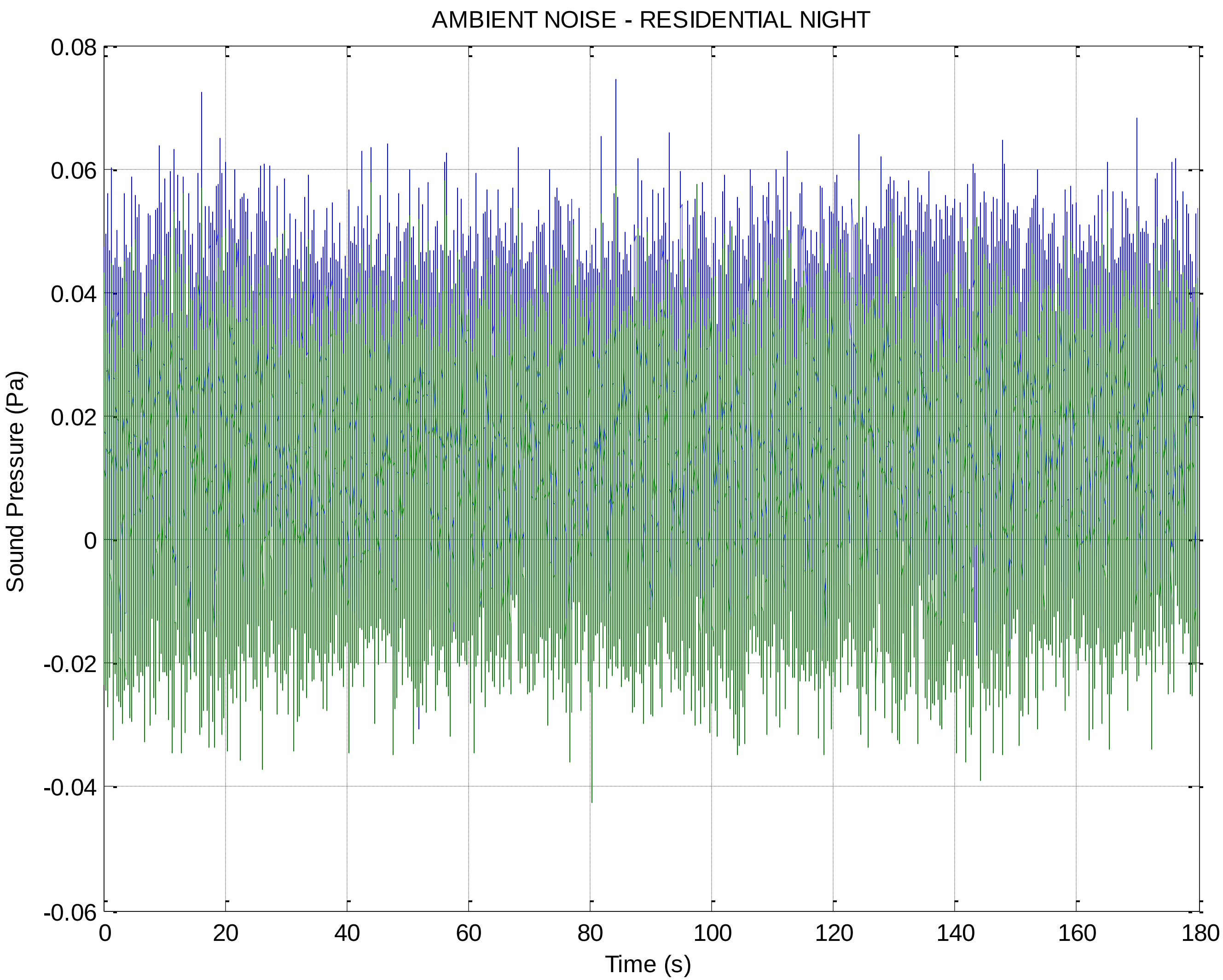
RESULTS – PROPERTY LINE MEASUREMENTS

RESULTS – AMBIENT NOISE



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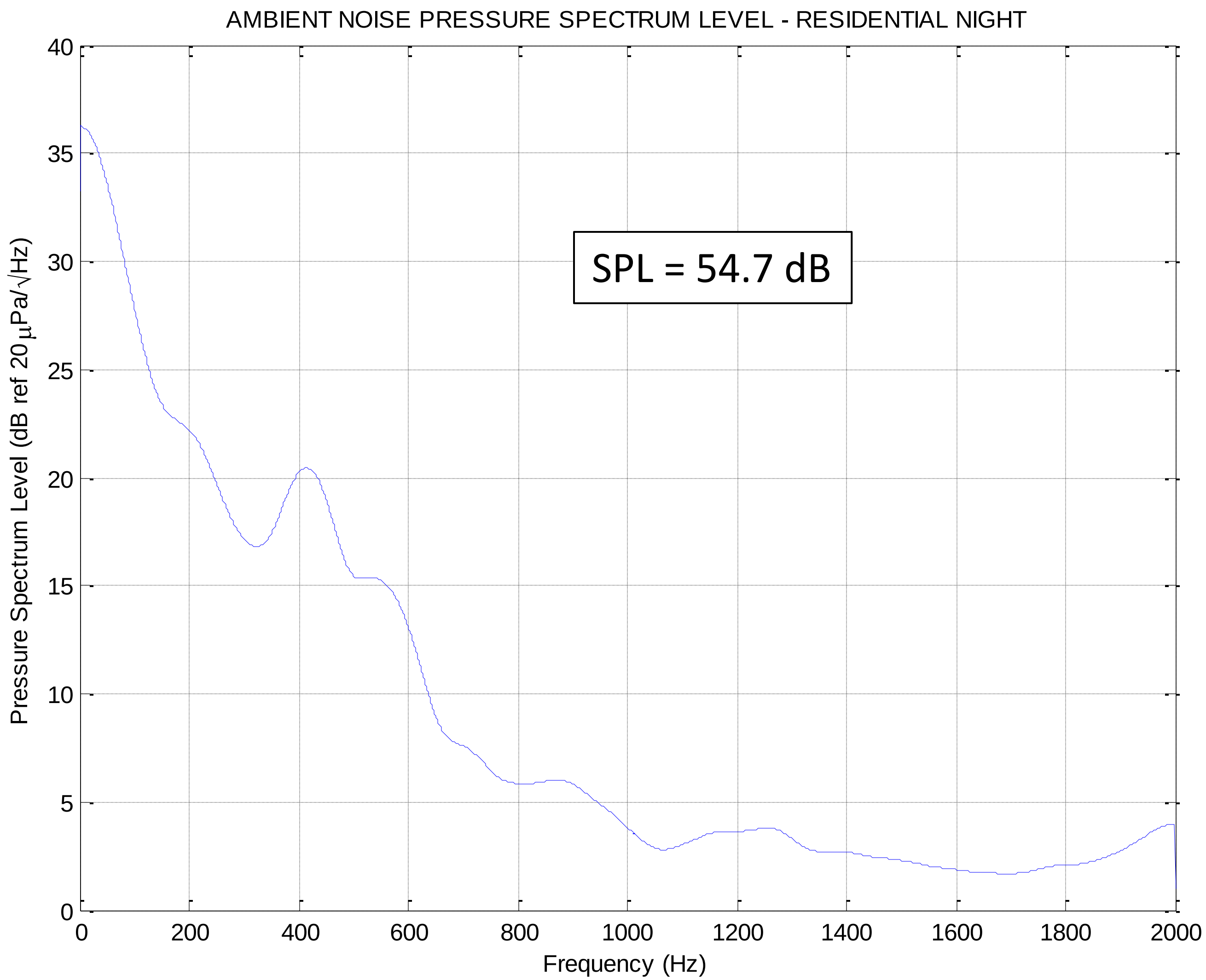
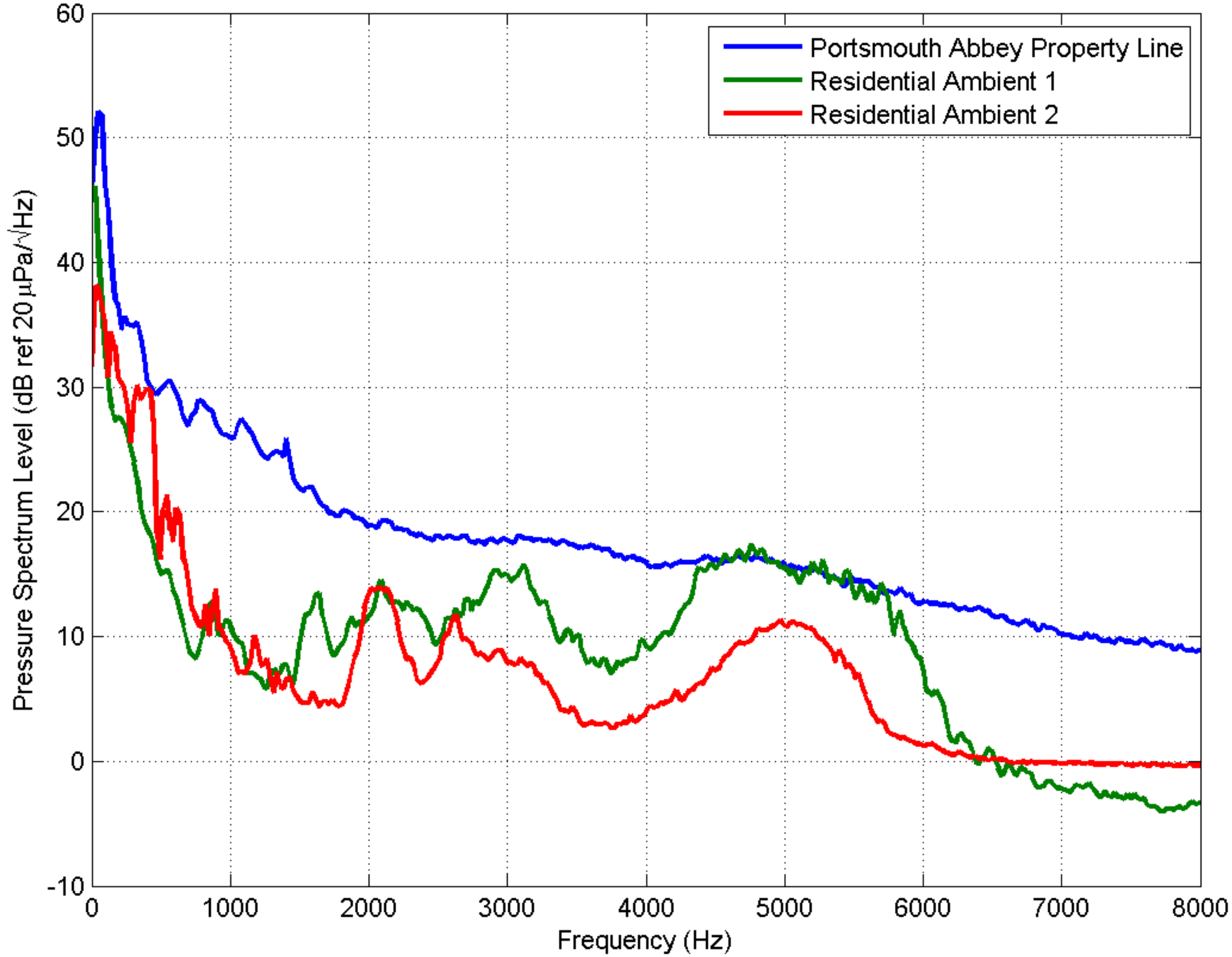


RESULTS – AMBIENT vs. PROPERTY LINE MEASUREMENTS



CONCLUSIONS

- Wind turbines produce measurable infrasonic and low frequency noise in the 1 Hz to 100 kHz band.
  - These levels were measured at an average of 84 dB SPL over this band with variation in time of up to16 dB.
  - A-weighting masks these levels (de-emphasizes infrasound levels by -20 to -150 dB from 100 Hz downto 1 Hz).

- The Sound Level Meter was not capable of measuring infrasound levels, and is not accurate for measuring audio band noise levels. The SLM measurements should be adjusted by adding 18 dB when using A-weighting and 9 dB when using C weighting.

- The Sound Level Meter is not capable of measuring transients, narrowband tonals or complex noise characteristics.

- The use of raw audio and infrasound recordings with appropriate processing allows computation of un-weighted levels and can reveal complex time-frequency behavior of the wind turbine noise.

- The description of either wind turbine or ambient noise is not adequately characterized by a single SPL number.

- It is feasible to map the spatial extent of the sound field surrounding turbines utilizing Geo-referenced and time synchronized audio recordings. However, the data indicate that it is not feasible to generalize the noise level behavior as a function of distance due to the variability and directionality of the wind turbine noise.

- It is not possible to make any conclusions regarding turbine noise levels relative to ambient noise levels at the property lines of the currently installed wind turbine locations.

Next Steps

- The acoustics study will be available on OER's website next week: www.energy.ri.gov
- OER and SPP will review the results of the property value and acoustic studies and determine any further guidance from the State regarding land-based wind energy siting
- Questions? Email danny.musher@energy.ri.gov

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